MINING POTENTIAL IN NORTHERN AND SOUTHERN CANADA: Guidelines for Regional Development Policy

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Foreword

"Conventional wisdom" often forms the basis for decisions in many aspects of the economy. Unfortunately, however, conventional wisdom often outlives the reality from which it arises. One such instance is exposed in this study by Verleun and Mackenzie, where the authors examine the widely-held premise that "more remote" means "less economic" for mineral exploration and development. They find that, in fact, more remote can be more economic, and they urge corporate and government planners to integrate this new information into their planning process.

Views expressed are those of the authors, and do not necessarily represent the views of the Centre for Resource Studies or its sponsors.

Margot J. Wojciechowski
Centre for Resource Studies

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Summary

Does "more remote" necessarily mean "less economic"? The fact that a greater proportion of base metal exploration is currently taking place in Canada's provinces than in the Yukon and Northwest Territories, seems to indicate that those who decide where to spend exploration dollars do believe that more remote does mean less economic.

The purpose of this study is to examine the potential cost, risk, and return characteristics of base metal supply to establish a means of comparison between northern and southern Canada. More specific objectives are to distinguish between the two areas by comparing the quality and viability of their base metal resources, by analyzing time trends, the influence of geological regions and deposit types, and the return characteristics of economic discoveries, and by assessing the direct effects of government mineral policies, especially mining taxation. The latter comparison also provides support for mineral policy formulation relating to infrastructure and northern development.

The analysis is based on extensive data relating to the Canadian base metal sector, assembled and updated on a continuing basis at the Centre for Resource Studies since 1975, and on a wide range of published sources, private surveys, internal government reports, and confidential mining company studies. The data base gathers exploration expenditures, possible economic discoveries for evaluation, projections of long-term metal prices, ore reserves and costs for individual deposits, generalized net smelter return conditions and deposit costing relationships, infrastructure estimates, and remoteness costs.

The resulting set of "base case" conditions enables the study to evaluate and compare the economic potential of base metal supply in the territories and provinces. The evaluation is carried out on a potential value basis, and on an after-tax basis.

The main conclusion of the study is that the economic potential of base metal exploration and mining in the Yukon and Northwest Territories is significantly more attractive than in the provinces of southern Canada; in other words, "more remote" does not in this case mean "less economic". The expected value per economic discovery was found to be $200 million in the territories, compared to $89 million in the provinces, with an expected rate of return on investment of 32 percent in the territories as compared to a 16-percent return in the provinces.

There is a double explanation for this conclusion. First, the average exploration expenditure required to discover an economic deposit is lower in the territories than in the provinces - $12 million as opposed to $43 million under base case conditions. Second, the average expected return from development and production for an economic deposit in the territories and the provinces is similar.

These two facts can in turn be explained by the following. Greater bedrock exposure in the territories, particularly the barren land surface above the treeline, is conducive to more efficient exploration than in the south. Also, depletion tends to be more advanced in the provinces, necessitating deeper, more costly exploration programs. Northern discoveries, occurring closer to the surface, can be worked with less expensive mining methods, offsetting the high locational costs associated with their development. While base metal deposits in the territories are remote in a two-dimensional geographic sense, deposits in the provinces are becoming increasingly remote in the third dimension: depth below the surface.

Study results demonstrate that base metal mining in the territories lags at least 20 years behind mining in the provinces. It is this time lag that is put forward as the main reason for the superior economic potential of northern Canada.

In spite of the above, even in the mid-1980s, at least 85 percent of base metal mining activity is concentrated in the provinces. It is our hope that both corporate and government decision makers will initiate major investment programs to take advantage of the mining potential in northern Canada.

Résumé

Les régions éloignées doivent-elles être nécessairement associées à une faible rentabilité. C'est ce que semblent penser les gestionnaires de l'industrie minérale canadienne responsables des dépenses d'exploration. Ainsi, dans les faits, une plus grande portion de l'exploration pour les métaux usuels se fait à l'intérieur des provinces plutôt qu'au Yukon et dans les Territoires du Nord-ouest.

Cette étude a pour but d'investiguer au sujet du coût, du risque et du rendement potentiel lié à l'offre des métaux usuels afin d'établir un outil de comparaison entre les économies minières des métaux de base du nord et du sud canadien. Plus précisément nous visons à distinguer les deux régions selon les points de comparaison suivants: la qualité et la viabilité de leurs ressources en métaux de base, l'analyse des séries temporelles, l'influence des régions géologiques et des types de gisements, les rendements associés aux découvertes et enfin l'évaluation de l'impact direct des politiques minérales des gouvernements, spécialement en taxation minière. Cette dernière comparaison sert de base pour supporter la formulation d'une politique minérale concernant l'infrastructure et le développement nordique.

La partie analytique de notre étude repose sur une banque de données exhaustive reliée au secteur minéral canadien. Ces données proviennent du CRS par l'entremise duquel elles ont été amassées et mises à jour depuis 1975. Elles proviennent en grande partie de rapports gouvernementaux internes, d'études éditées par le secteur privé et finalement d'études confidentielles produites par les compagnies minières. La banque de données inclut les dépenses d'exploration, des découvertes économiques potentielles, des prévisions à long terme des prix des métaux, les réserves en minerai et les coûts pour les gisements individuels, la fonction de fonderie généralisée et les fonctions de coûts généralisées, des estimations concernant l'infrastructure et les coûts associés à la localisation.

L'ensemble des résultats obtenus à l'aide de cas témoins permet d'évaluer et de comparer l'offre potentielle des métaux de base dans les territoires et les provinces. L'évaluation est effectuée avec des valeurs potentielles nettes d'impôt.

La conclusion principale de notre étude est que le potentiel économique relié à l'exploration et à l'extraction minière des métaux de base est nettement plus attrayant dans le Yukon et dans les territoires

du Nord-ouest que dans les provinces du sud canadien. En d'autres mots, l'éloignement n'est pas intrinsèquement lié à une plus faible rentabilité. La valeur estimée par découvertes est de $200 millions dans les territoires en opposition aux $89 millions rattachés aux provinces. Cela représente un taux de rendement interne respectif de 32 percent et de 16 percent pour les territoires par rapport aux provinces.

Le revenu anticipé du développement et de la production dans les TNO est similaire à celui des provinces. Ainsi la rentabilité supérieure des TNO s'explique par des dépenses d'exploitation plus faible ($12 million pour cette region contre $43 millions dans les provinces).

Plusieurs facteurs expliquent cette différence de coûts. La plus grande accessibilité au socle rocheux dans les territoires, particulièrement dans les régions de toundra, permet une exploitation plus efficace que dans le sud. De plus, l'épuisement accentué des ressources dans les provinces requiert une exploration plus en profondeur et plus coûteuse. Les dépôts nordiques étant plus en surface peuvent être explorés à moindre coût ce qui compense pour le coût plus élevé de développement associé à la localisation. Bien que les dépôts de métaux de base dans les territoires soient éloignés de façon bidimensionnel au point de vue géographique, les dépôts des provinces par contraste le sont dans la troisième dimension: la profondeur.

Les résultats de l'étude démontrent que l'exploitation minière dans les territoires a au moins 20 ans de retard sur celle des provinces et c'est ce retard qui est mis de l'avant pour justifier la rentabilité potentielle enfouie dans le nord canadien.

En dépit de ce qui précède, l'activité minière des métaux de base en ces années '80 est toujours concentrée à 85 percent dans les provinces. C'est notre espoir que les entreprises et les gouvernements initieront un programme d'investissement majeur afin de profiter du potentiel minier du nord canadien.

1. INTRODUCTION

Pushing Back the Mining Frontier

From the outset, mining has been a vital force in pushing back the Canadian frontier. The original explorers of this land - most notably, Cabot, Cartier, Frobisher, Champlain, and Hearne - backed by expectant regal and commercial investors, were inspired to venture into the unknown by prospects of precious metals and gemstones.

In the early 1860s, placer gold discoveries in British Columbia justified construction of a 640-km road through challenging terrain from Yale to Cariboo. The settlement of the interior which followed, as well as the anticipation of more goldfields, stimulated interest in the newly united eastern colonies for communication with the remote west coast, then virtually cut off from the rest of Canada. This led to a singular national achievement following confederation: the building of the transcontinental railway.

This process of mineral-led exploration and development of regions remote from existing population centres and infrastructure has continued to the present.[1] A brief look at the economic geography of Canada shows that communities established in remote areas frequently have their origins in mining; Sudbury, Timmins, Kirkland Lake, Cobalt, Rouyn-Noranda, Trail, Kimberley, Val d'Or, Yellowknife, and Red Lake, are among the early mining centres. Growing mineral import demands after

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[1] The history of exploration and mining in Canada is recounted in the following texts.

A. Hoffman, *Free Gold: The Story of Canadian Mining*, Associated Book Service, New York, 1958.

D.M. Le Bourdais, *Metals and Men: The Story of Canadian Mining*, McClelland and Stewart, Toronto, 1957.

J. Carrington (ed.), *Risk Taking in Canadian Mining*, Pitt Publishing, Toronto, 1980.

M.R. Hanula (ed.), *The Discoverers: A 50-Year History of the Prospectors and Developers Association, Some Famous Prospectors, and their Discoveries*, Pitt Publishing, Toronto, 1982.

W.G. Richardson, *A Survey of Canadian Mining History*, CIM vol. 14, Canadian Institute of Mining and Metallurgy, Montreal, 1974.

1945, particularly from the United States, stimulated a major expansion in the size and geographical extent of the Canadian mineral economy, giving birth to mining towns such as Manitouwadge, Chibougamau, Bathurst, Mattagami, Thompson, Logan Lake, Pine Point, Labrador City, Faro, Joutel, Lynn Lake, and Leaf Rapids. Even in the 1980s, mining continues to open frontier areas - Tumbler Ridge, the Athabasca basin, Lupin, Polaris, Detour Lake, and Hope Brook for example. As a result, the Canadian mineral sector is geographically diverse, spread throughout the nation in a way unequalled by any other industry. Mining clearly has played a central role in regional development.

As the focus of mining activities moved out into the hinterland, regional infrastructure networks were extended. In addition to the establishment of new communities, power, communication, and transportation linkages were required. Most new railroad development in Canada since the end of World War II has been directly related to the mineral sector.[2] Mining was also the driving force behind much of the new harbour and airport facilities, and many power developments were built to serve mining operations. In new areas, infrastructure accounts for a substantial part of the total capital cost of mineral development.[3]

By the early 1970s, the spreading out of transportation and social infrastructure from the southern fringes of an immense landmass had combined with abundant, high-quality resources, a well motivated work force, entrepreneurial spirit, and a strong work ethic to enable the Canadian mineral economy to become the third largest in the world. There is every reason to believe that the historical pattern of mineral exploration and development continually extending into less-accessible, usually more northerly, areas of Canada will continue until the mining frontier is pushed back to its ultimate physical limit.

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2 A compilation made by Wallace shows that approximately 5800 km of new railway lines were constructed in Canada during the 1950-75 period. Mining accounts for well over 90 percent of the total length. See Iain Wallace, *The Transportation Impact of the Canadian Mining Industry*, Centre for Resource Studies, 1977, pp. 23-25.

3 For example, infrastructure costs accounted for 78 percent of the capital cost of the Pine Point project in the Northwest Territories, and for 42 percent of the cost of the original Faro development in the Yukon. See *Mineral Policy: A Discussion Paper*, Energy, Mines and Resources Canada, December 1981, pp. 73-74.

Underlying Economic Rationale

Comparative Costs and Benefits

What economic factors underlie the phenomenon of pushing back the mining frontier?

Like all investment decisions, the choice between mineral exploration and development in frontier areas and mineral exploration and development in established districts is based on a trade-off of costs and benefits. The locational costs associated with mining in frontier areas are no doubt substantially higher than in established mining districts. Distances from major population centres, sources of supply, and mineral markets are greater. As a result, travel times are longer, and transportation costs higher; wage and salary premiums are necessary to attract and retain a productive workforce; and the cost of social, transportation, and power facilities typically are high, relative to older mining areas where the infrastructure needed for new mining activities is already in place.

Yet, we can see more mineral investment reaching out further into the northern hinterland. The frontier-area opportunity must thus be viewed, at least by some, as more attractive than established mining districts. What offsetting benefits justify this choice? Generally, the incentive to shift investment into increasingly remote areas arises because of the continual depletion of ores taking place at operating mines in the established districts. As higher-quality mineral resources are exhausted, exploration and development in the older areas must focus on fewer, smaller, deeper, and lower-grade targets. As the economic consequences of these depletion effects begin to outweigh the higher locational costs associated with more-remote activities, there is an incentive to shift investment towards the higher quality resources still awaiting discovery. In other words, frontier areas are favoured when the greater geological potential offered is perceived to offset the higher locational cost burden. Canadian history shows how this economic incentive has extended the mining frontier into less-accessible areas.

The comparative costs and benefits which determine the extensive geographical limits of mining investment are also shaped by several other factors. These include:

- differences in inherent geological potential among areas;
- advances in exploration, mining, and processing technologies;

- unexpected discovery of high-quality deposits in established districts;
- changing growth rates in the demand for mineral products;
- long-term trends and short-term fluctuations in mineral commodity prices.

Nevertheless, it is the fixed size, variable quality, and exhaustible nature of mineral deposits which inevitably push back the extensive margin of mineral exploration and development.

Degrees of Remoteness

The strategic choice between investment in established districts and frontier areas is, in reality, a continuum. In the Canadian context, increasingly remote exploration and development may be categorized into regions:

- within older mining districts;
- in those settled parts of the provinces which lie outside established mining districts;
- within less-accessible provincial areas;
- in the southern parts of the Yukon Territory and the Northwest Territories served by roads and railways;
- along the north coast and on the arctic islands accessible in the summer by ocean transport;
- within the barren lands of the middle north which are inaccessible today except by airplane and, in some cases, winter roads.

For the purpose of our study, this continuum is split into two parts - "the provinces", which mainly encompass the first three groupings, and "the territories", which include the last three categories. This broad division of Canada into more-accessible and frontier regions enables us to examine empirically the economic trade-offs between locational costs and geological potential.

Unit Value of Mineral Product

The transportation component of locational costs is an inverse function of the unit value (or, price per unit weight) of the mineral product.[4] Mines which produce high unit value commodities - gold or silver bullion, gemstones, or uranium concentrate, for example - generally require less capital-intensive infrastructure, and their economic viability is therefore less sensitive to remoteness. Also, development may be justified on a relatively small scale, based on air transport. This explains why gold, silver, and uranium have been at the forefront of mineral development in the Canadian north.[5] Lupin provides a notable current example: a large gold mine, located in the remotest part of the middle north, successfully brought into production utilizing the airplane as the sole mode of transport.[6]

Medium unit value mineral commodities such as base metal concentrate and ferroalloy (nickel and tungsten, for example) concentrate require all-weather surface (road, rail) and or ocean transport. The economic viability of producing these commodities is thus much more dependent on location and, to justify investment, the comparative quality of mineral resources in frontier areas must be correspondingly higher. Also, more substantial volumes are required to distribute the capital-intensive infrastructure costs. In Canada, investment in zinc, copper,

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4 Although the classification is somewhat arbitrary, for this discussion mineral products are grouped into the following three categories.

High unit value: greater than $500 per tonne.
Medium unit value: $100-$500 per tonne.
Low unit value: less than $100 per tonne.

5 More generally, the historical worldwide pattern of gold rushes illustrates this phenomenon.

6 For the 19 months of mine development, everything had to be flown in - about 22,000 tonnes in total. The Lupin site, about 80 km south of the Arctic Circle in the northeast Mackenzie district of the Northwest Territories, was too far from the water route, and 400 km away from the nearest road at Yellowknife. A Hercules aircraft was used to transport construction equipment, building supplies, and mining machinery. Most of the 1250 flights originated at Yellowknife. However, the heaviest loads, involving the ball mills and diesel generators, were airlifted from Edmonton, 1300 km distant. See "Lupin Gold Mine", G.A. Peer, Heavy Construction News, June 7, 1982.

Since the start of production, the mine has operated a 560-km winter road from the all-weather highway which extends 80 km north of Yellowknife. The winter shipping season takes place between mid-January and mid-April.

nickel, and tungsten exploration and development has generally followed the path established by precious metal mining into more remote northern regions.

Iron ore, coal, and most non-metallic minerals are low unit value commodities. Here, transportation costs usually represent the major component of the delivered market price. These commodities require dedicated rail, port, and bulk ocean transport systems and very large production volumes to be competitive in international markets. Remote area developments of low unit value mineral deposits are rarely viable.[7] The northeast coal project in British Columbia illustrates the massive investment and high risk associated with implementing a mining project of this type.

For study purposes, we focus on the locational costs, quality, and viability of base metal resources in the territories and provinces of Canada. There are several reasons for selecting base metals for our case study, not least of which is that a Canada-wide data base has already been established to facilitate the north-south comparison.[8] Also, base metal potential is considered to be of a high order, important to regional and northern development, and sensitive to location.

Mining Company Planning

Company programs and projects are typically spread across a variety of geographical locations, particularly in the exploration phase. The planning issue facing the company is how to best balance investment as a function of remoteness. A company can consider both alternatives - pushing back the frontier and investing in established districts - they are not mutually exclusive and a range of options is available. Since individual companies have particular objectives, resources, and cost-risk-return perceptions, emphasis varies widely in this regard. Some tend to

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7 There are exceptions where ores are of a particularly high quality and very large production volumes can be marketed: for example, iron ore developments in the Pilbara region of Australia in the 1960s, and the more recent implementation of the Carajas operation in Amazonia.

8 The data have been assembled on a continuing basis since 1972. For example, to see the historical roots for the present work, the interested reader can consult B.W. Mackenzie and M.L. Bilodeau, *Effects of Taxation on Base Metal Mining in Canada*, Centre for Resource Studies, Queen's University, Kingston, 1979, 190 pp.

concentrate on older areas where they have particular strengths. Others, such as Cominco and Echo Bay, have emphasized frontier exploration and development. It is not unusual for companies to set strategic boundaries beyond which they do not explore. The emphasis adopted is, of course, related to the unit value characteristics of the commodities sought.

Some exploration organizations, mining companies, and government agencies question the economic rationale of the historical trend towards increasing levels of exploration and mining in less-accessible areas, particularly in Canada's north. The reason for their scepticism is apparently a tendency to equate "more remote" and "higher cost" with "less economic". A commonly-held perception is that mining in the north is more risky and less economic than in the more favourably located areas of southern Canada. Our study examines the validity of this conventional hypothesis.

Government Policy Setting

Historical Review

Government policies relating to the provision of mining infrastructure are inextricably linked to those concerning regional and northern development. Starting in the 1860s when British Columbia Governor James Douglas decided to build the Cariboo road and continuing to the present day, public infrastructure policy has profoundly influenced the regional pattern of mineral activities in Canada.

Much of the mineral wealth in the southern shield and western cordilleran regions was made accessible thanks to the construction of the transcontinental railway system in the period 1880-1920.[9] Sustained economic expansion of the Canadian mineral sector in the 1950s and 1960s was supported by the active interest of federal and (where relevant) provincial governments in promoting the social and economic development of northern frontier regions. During this period, government

[9] This section draws on Iain Wallace's review of mineral-related infrastructure developments and policies in Canada, "Mineral Resource Transportation and Frontier Infrastructure Provision in Canada", pp. 105-117 in *Regional Impacts of Resource Developments*, edited by C.C. Kissling et al., Croom Helm Australia, 1984, 285 pp.

provided extensive support for infrastructure such as access roads, air strips, and rail lines.

Public sector aid to promote resource development and provision of the necessary infrastructure thus was politically acceptable at a time when international market forces were already strongly supportive of the northward expansion of Canadian mining. In this growth era, over 4000 kilometres of railway lines were built to gain access to new mine developments. Notable in this regard was the construction in the early 1950s of a 575-km rail line by the Iron Ore Company of Canada. The line started at the deep-water terminal at Sept Isles and ended at the iron ore deposits in the Schefferville region of new Quebec and Labrador. Also important was the $75-million public sector investment in the mid-1960s to build the 690-km Great Slave Lake railway to connect the Pine Point zinc-lead development to the continental railway system. In the 1950s, the St. Lawrence Seaway was constructed at public expense on an intended cost-recovery basis. The "roads to resources" program, introduced by the Diefenbaker government in the early 1960s to open up areas potentially rich in natural resources, resulted in the building of 5000 km of development roads backed by federal expenditures of another $75 million. While these public sector investments were supported by mining production, they also provided an important up-front incentive for mineral exploration and development.

From the early 1970s, a number of factors - including maturing mineral markets, continuing change in tax policies, environmental concerns, native land claims, and the prolonged global recession of the 1980s - have led to a considerable change in mining company perceptions of the attractiveness of exploiting Canada's frontier mineral resources, as well as in the enthusiasm of governments for this form of development. There has been a mixture of policy responses. The Nanisivik mine, developed on Baffin Island in the mid-1970s, was assisted by the federal government with a view to demonstrating the viability of mineral development in the far north, gaining experience with arctic shipping, and promoting native training. An innovation of this project was the government's decision to treat its investment in project-specific infrastructure as earning an 18-percent equity interest. On the other hand, the infrastructure for Cominco's Polaris mine which opened in 1982, a similar type of zinc-lead operation on Little Cornwallis Island in the high arctic, was entirely company funded.

The Faro mine in the Yukon presents a more complex and ongoing policy concern. This development was initially stimulated in the late-

1960s by $27 million of federal government assistance for road construction and upgrading, the provision of electric power service, and the development of a town site. The mine was closed in 1982 due to depressed zinc and lead prices, and high unit operating costs. Federal aid in various forms was provided for redeveloping the mine from 1983, the resumption of operations being regarded as central to reviving the Yukon economy. At a time of weak metal markets, this government intervention was strongly criticized by other Canadian producers. Under new ownership, the Faro mine recommenced production in late 1986. A remarkable turnaround was achieved in 1987. With 430 employees, the rate of production was 50 percent higher than the output realized in 1981 with 720 employees. The unit operating cost was about half that incurred in 1981, all commitments with the previous owner and government were settled, and a positive cash flow position was attained. What has been debated here is the issue of government's role at a time of depressed markets in reactivating apparently marginal production in a resource-based frontier region, at the possible expense of development and production cutbacks elsewhere in the country.

The northeast British Columbia coal project, which commenced commercial shipments in 1984, fits into the traditional pattern of government support. Total costs of $2.8 billion include over $1 billion of public spending on infrastructure. The largest component of this is the approximately $490 million spent by the British Columbia Railway to construct a 130-km branch line across the western cordilleran to link the coalfield to the existing rail network.

This brief historical review suggests that public sector involvement in the provision of infrastructure and regional development relating to mining reflects more a series of *ad hoc* project-specific decisions than the application of a consistent set of criteria for judging the desirability, necessity or extent of government support. Complicating the formulation of coherent policies for regional infrastructure is the fact that the overall responsibility of the federal Department of Energy, Mines and Resources (EMR) for national mineral policy is delegated, with respect to the northern territories, to the Department of Indian Affairs and Northern Development (DIAND), while elsewhere, provincial governments have primary responsibility for mineral policy. In recent years, both territorial governments have been gradually assuming provincial-level responsibilities from DIAND, further tangling the public decision-making process.

Issues of the 1980s

The 1981 federal government mineral policy discussion paper devotes separate sections to "infrastructure" and to "northern and regional development".[10] It notes that since Canada's vast northern regions are believed to host substantial undiscovered mineral deposits, and since mineral exploration in the more accessible southern regions has by no means been exhaustive, the federal government must continue to encourage regional mineral development. However, government investment in infrastructure should not be undertaken simply for the sake of opening up a region. The guiding principle in choosing among alternatives, according to the discussion paper, must be the promotion of highly productive activities that augment national per capita income. Thus, if the federal government is to be involved in the provision of infrastructure for entirely new mining areas or for remote mineral projects, it should do so in ways that minimize risk to its capital by ensuring multiple uses of infrastructure, and provide opportunities for sharing in profits indirectly resulting from its infrastructure investment, through user fees and/or progressive taxes.

Mining company reaction to the discussion paper almost universally rejected the idea of government equity participation, contractual profit sharing, user fees, or progressive taxation as conditions for federal provision of infrastructure.[11] There is a strong feeling that government already shares adequately in the upside profits of mineral development, through the taxation system. The industry, however, feels the federal government must assume a crucial role in providing infrastructure for new mining areas.

A changing and conflicting mixture of objectives is implicit in past government policy decisions concerning infrastructure support in remote regions. These objectives include:

- letting industry meet its own needs;

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[10] *Mineral Policy: A Discussion Paper*, pp. 73-81.

[11] See *Canadian Mineral Policy Formulation: A Case Study of the Adversarial Process*, D. Yudelman, Working Paper 30, Centre for Resource Studies, Kingston, 1984, 83 pp.

- subsidizing new investment activity which would otherwise be uneconomic on the basis of a project's contribution to the attainment of other desirable policy goals;
- giving assistance so that private investment in remote areas is no more onerous than in more-accessible regions where infrastructure is publicly provided;
- facilitating development by enabling the cost of common infrastructure facilities to be shared among projects and over time;
- responding in order to sustain the viability of a mineral-dependent economy threatened with severe decline.

The timeframe and geographical focus also vary, from concern for a specific project, to regional, provincial and territorial interests and, ultimately, to the promotion of national economic and social development.[12]

While public policy is sooner or later a matter of political judgment, a coherent policy framework of lasting value requires explicit attention to the assessment of costs and benefits associated with the options available. Thus, it may be desirable and possible to move from the *ad hoc* judgments of the past to the establishment of a more desirable and sustainable ongoing relationship between private mineral investment and public infrastructure services in remote regions.

With these requirements in mind, DIAND issued a mineral sector discussion paper in early 1985. Following consultation with the territorial governments, the mining industry, and native organizations, a new policy was announced towards the end of 1986. This Northern Mineral Policy was endorsed during 1987 in a broader mineral policy statement made by EMR on behalf of the Government of Canada.[13]

The new policy for the Canadian north is strongly pro-development and pro-mining. It is founded on recognition that:

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[12] The link between provision of infrastructure for mining and establishment of more broadly-based economic development is a policy issue of wide interest. For example, Ciaran O'Faircheallaigh provides relevant empirical evidence through case studies of four mining projects in Australia. See *Mine Infrastructure and Economic Development in North Australia*, Working Paper 36, Centre for Resource Studies, Kingston, 1986, 92 pp.

[13] See *The Northern Mineral Sector: A Framework for Discussion*, Indian and Northern Affairs Canada, March 1985, 37 pp.; *The Northern Mineral Policy*, Indian and Northern Affairs Canada, December 1986, 31 pp.; *The Mineral and Metal Policy of the Government of Canada*, Energy, Mines and Resources Canada, May 1987, 13 pp.

- a healthy economic base is essential for supporting improvements in the well-being of northern residents and protection of the environment;

- economic development of the Yukon Territory and the Northwest Territories is essentially dependent on mining.

Thus, the Northern Mineral Policy makes the point unequivocally that the federal government wishes to promote realization of the region's mineral resource potential.

The prime objective of the announced policy is to improve the climate for investing in, and the competitive position of, the mineral sector in the territories. Attention is given to providing the mining industry with the atmosphere of stability it requires with regard to mining legislation, access to land, native land claims, and conservation initiatives. The competitiveness of the northern mineral sector in world markets is discussed in terms of mining royalty regimes, regulatory systems, geoscience information, and infrastructure for mining.

While the Northern Mineral Policy furnishes a coherent and logical framework, no new federal funding has been provided to achieve its objective. This policy initiative now needs to be followed up with appropriate government programs to give it meaning.

If the federal government intends to act on the Northern Mineral Policy, a factual understanding will be required of the economic potential existing in northern frontier regions relative to the potential remaining in the more-accessible mining districts in the provinces. The present study examines the ingredients necessary for this type of comparative economic assessment, and analyzes and explains case study results for Canada's base metal resources. The purpose of doing so is to support the process of implementing mineral policy.

Base Metal Mining in Canada

Base metal resources have played an integral part in the growth and development of mining in Canada. The constituent commodities - copper, zinc, lead, molybdenum, and byproduct gold and silver - require

similar exploration, development, and production technologies, and form a consistent grouping in terms of sources of information.[14]

During the first half of this century, Canadian base metal supply was derived primarily from three major mineral deposits: the Sullivan zinc-lead mine in southern British Columbia; the Flin Flon copper-zinc-silver mine in northern Manitoba; and the Horne copper-gold mine in northwestern Quebec. Base metal supply in the period since World War II has been characterized by rapid growth and extensive geographical diversification. Discoveries and developments of importance include:

- copper-gold deposits in the Chibougamau region of Quebec;
- the Brunswick orebodies and other zinc-lead-copper deposits in the Bathurst region of New Brunswick;
- the Geco copper-zinc-silver mine in northern Ontario;
- copper-zinc deposits in northern Manitoba;
- base metal deposits in the Mattagami and Noranda regions of Quebec;
- large low-grade copper and copper-molybdenum deposits in British Columbia;
- the Pine Point complex in the Northwest Territories;
- the Kidd Creek zinc-copper-lead mine in the Timmins region of Ontario;
- the Faro zinc-lead-silver mine in the Yukon;

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[14] While the meaning of the term "base metals" is admittedly controversial, the definition adopted here is widely recognized. Base metals are the metals which the ancient alchemists tried to convert into gold or silver - usually they include copper, lead and tin - hence the term "base". Today zinc is included in the group, mainly because many mines produce zinc along with lead. For the same reason, we have included molybdenum, which is in some cases the byproduct of copper mining, and the gold and silver byproducts of base metal mining. Canada had no primary tin discoveries of economic interest within the study period. Nickel and tungsten are usually considered to be ferroalloys rather than base metals because their most important use is in steel making.

Our analysis utilizes an extensive historical timeframe of data including $3.4 billion of exploration expenditures and 291 significant mineral deposits. Thus, the "base metal" sector provides the foundation for a statistically and practically meaningful case study comparison of the long-term mining potential of northern and southern Canada.

- base metal deposits at Nanisivik and Polaris in the high arctic.[15]

The value of production from the Canadian base metal sector increased from $2.2 billion in 1975 to $4.1 billion in 1980. The prolonged world-wide recession then drove revenue down to $3.0 billion per year in 1982 and 1983. The value of base metal production averaged $3.8 billion per year during 1984-86 before rebounding to $4.7 billion in 1987.

The base metal sector accounts for 40-45 percent of the value of Canada's metallic mineral production. Canada ranks first in the world as a producer of zinc, third in silver, molybdenum and gold, and fourth in copper and lead.

Production of copper and zinc, the two most valuable constituents of Canada's base metal resources, is impressive. Cumulative Canadian output to 1987 is 25 million tonnes of copper and 33 million tonnes of zinc, valued at $98 billion and $43 billion respectively using December 1987 prices.

Base metal mining is central to the comparison of mineral potential in the territories and provinces because of its relative importance, and because it is highly dependent on regional infrastructure. While high quality gold mines, such as Lupin and Salmita, can be developed and operated using aircraft and winter roads, base metal mining requires all-weather surface transportation facilities. Base metal resources from Canada's traditional mining districts, although continuing to offer attractive opportunities for new discoveries, have already been intensively explored, developed, and mined. As we look out towards the turn of the century, the economic rationale for shifting the extensive limits of base metal mining into more remote northern frontier areas is thus becoming an increasingly interesting and vital issue.

[15] This evolution of base metal discoveries and development correlates with the previously outlined geographical diversification of mining communities.

Mining in the Territories[16]

Setting

The Yukon Territory and the Northwest Territories lie north of latitude 60 degrees, covering an area of 3.86 million square kilometres, with dimensions from east to west of 3500 km and from north to south of 2500 km. This northern region, comprising 40 percent of Canada's landmass, is sparsely populated with only 73,000 people. Almost half of the population is of native origin.

Since the Klondike gold rush of 1898, mining has been the mainstay of economic activity in the territories. Production from these placer deposits peaked in 1900 and then rapidly declined. The value of mineral production in the territories realized in 1900, corrected for inflation, was not attained again until the mid-1960s. Nevertheless, there were notable mining achievements in the intervening decades, including:

- copper production from the Whitehorse copper belt;
- discovery and development of high-grade silver deposits in the Keno Hill-Galena Hill area;
- production of radium and silver, and subsequently uranium, at the Eldorado mine on Great Bear Lake;
- large-scale dredging of the Klondike gold placers;
- exploration and development of the Yellowknife gold camp, including the Con and Giant mines;
- development of the Rankin nickel mine on Hudson Bay.

A remarkable period of growth in mining activities occurred in northern Canada from the mid-1960s to the end of the 1970s. Driven by buoyant metal prices, the value of mineral production in both the Yukon and Northwest Territories experienced eightfold increases in constant money terms. The start-up of major zinc-lead mines at Pine Point in 1964 and at Faro in 1970 led the way. Other new operations included the Cantung tungsten mine, a resumption of production from the Whitehorse copper belt, the Clinton Creek asbestos operation, silver

[16] The synopsis presented here has been mainly excerpted from the following sources: D.D. Brown and T.W. Caine, "The Mining Industry in Canada's Northern Territories - Past, Present and Future", *CIM Directory*, 1986, pp. 67-92; *The Northern Mineral Sector: A Framework for Discussion*; *The Northern Mineral Policy*.

mining in the Port Radium area, and the Nanisivik zinc-lead mine on Baffin Island which started in 1976.

The worldwide depression in base metal markets in the early 1980s had a severe impact on the mineral economy of Canada's northern territories, particularly in the Yukon where the Faro mine was forced to close from 1982 to 1986. In 1987, the constant dollar value of mineral production in the Yukon was still only 85 percent of the record level achieved in 1980. The situation in the Northwest Territories was much better. Existing base metal mines managed to continue producing, and there were three new mine openings - the Lupin and Salmita gold mines, and the Polaris zinc-lead mine. Consequently, the value of mineral production in the Northwest Territories generally continued to increase, reaching an inflation-adjusted value in 1987 which was 55 percent higher than the 1980 level.

In 1987, there were 13 hardrock mines operating in both territories, producing zinc, lead, gold, silver, and tungsten. In addition, in the Yukon, some 150 seasonal placer mines recovered gold. Significant quantities of natural gas, petroleum, and structural materials were also produced.

The value of minerals produced in the Canadian north in 1987 totalled $1397 million: $447 million from the Yukon Territory, and $950 million from the Northwest Territories. This is equivalent to almost $20,000 for every northern resident. The four base metal mines - Faro, Pine Point, Nanisivik, and Polaris - accounted for about 60 percent of the total.[17]

The value of territorial mineral production is not large in overall Canadian terms. For example, in 1987 the territories accounted for 4 percent of total national mineral production. However, 13 percent of Canada's metallic mineral production comes from the north, including all the country's tungsten output, 60 percent of the lead, 36 percent of the zinc, 14 percent of the gold, and 12 percent of national silver output.

Role in the Regional Economy

Since the turn of the century, mining has played the major role in the economic development of the territories. In this vast area of Canada, trends in the value of mineral production and population, sparse as it is, have been closely correlated.

[17] The Pine Point mining complex, in production since 1964, closed in 1988.

Mining activities have provided the stimulus for the building of roads and railway lines into the territories, justified the construction of hydroelectric generating facilities, created numerous communities, encouraged the development of innovative technologies and, in so doing, have created thousands of direct and indirect jobs. Highlights of the historical evolution of transportation infrastructure in the north are:

- building the 176-km narrow gauge White Pass and Yukon railroad in 1898-1900 between Skagway and Whitehorse to provide improved transportation to the Klondike;
- opening the 2400-km Alaska highway in 1942 and the extension of roads in the Yukon to Mayo and Dawson during the 1950s;
- completion of the initial 752-km all-weather stretch of the Mackenzie highway from Grande Prairie to Hay River in 1949, followed by its extension to Yellowknife in 1961;
- construction of the Great Slave Lake railway in the early 1960s to Hay River with a spur line to Pine Point;
- building the highway from Carmacks to Ross River in 1968 to link the Faro mine into the Yukon highway system;
- development of ice-strengthened and ice-breaking bulk ships for transporting base metal concentrates from Nanisivik and Polaris.

The role of mining can be measured by its direct contribution to gross domestic product (GDP), a measure of the total flow of goods and services produced each year by an economy. With the broadening economic base of the territories, mining's direct share of GDP declined from 40 percent to 30 percent through the 1970s, and stood at about 25 percent in 1987. Nevertheless, because of the relatively simple economic structure of the Yukon and Northwest Territories and the restricted range of other opportunities, mining plays a much more important role than in other areas of Canada. For example, mining's direct contribution to GDP in the territories is about three times greater than in Newfoundland and about 15 times greater than in the other main mining provinces.

Traditionally, mining has been the largest private sector employer in the territories. Over the years, mining employment has remained relatively stable at about 11 percent of the labour force, or about five

times the Canadian average, while accounting for up to 25 percent of wages and salaries. In addition, mining creates a significant number of indirect jobs in the territories in transportation, electricity, construction, government and other service sectors, as well as in the rest of Canada. In much of the north, particularly in the barren lands, mineral exploration, mining, and associated service activities are the only practical alternative to employment in traditional hunting, trapping and fishing activities and related tourism opportunities.

The impacts of mining vary considerably with the type and location of projects and the structure of the regional economies. Large interior base metal mines, such as Faro and Pine Point, greatly benefit northern areas through the development of the required transportation and power infrastructure and new communities. Remote developments, such as gold mines in the barren lands and base metal mines located on the arctic islands, have fewer local impacts but do provide substantial benefits to southern Canada through their demands for goods and services. It is estimated that over the period 1978-1982, the Northwest Territories' mining industry spent on average about 28 percent of its annual costs (wages, salaries and taxes) in the Territories, while 58 percent was spent in the rest of Canada and 14 percent outside of Canada. Northern mines also contribute significantly to the Canadian balance of payments, since most of the north's mineral production is exported.

Clearly, mining is the mainstay of economic activity in the territories. The future development of the mineral sector will have a major impact on the growth of the northern economies.

Future Potential

The territories are generally viewed as offering attractive conditions for mineral exploration. As we will see, Canada's north comprises a favourable mixture of prospective geological regions and deposit types. Approximately 24 percent of the area has good surface exposure of bedrock, and 64 percent - the barren lands - lies above the treeline, facilitating the search for mineral deposits. In the provinces, by comparison, 20 percent of the area is characterized by good bedrock exposure, but only the tip of the Ungava penninsula and a small part of northern Manitoba, 4 percent of the landmass, reaches beyond the treeline.

It is only since the mid-1960s that large-scale and systematic exploration programs have been carried out in the territories. Some regions of the Arctic still remain relatively unexplored and a large part of the north has only been covered by low-intensity extensive programs, designed to discover specific commodity targets. Exploration for base metals, gold, and other mineral deposit types in most of the north is at a relatively early stage compared to the conditions which typically prevail in the southern provinces.

The territories currently account for 4 percent of the value of Canada's mineral production. With 40 percent of the landmass, and promising geological domains which are still relatively unexplored, the mineral resource potential of the north is obviously immense. Regarding the long-term prospects for mining activity, this potential has to be weighed up in relation to the relatively high costs associated with the north's remoteness and harsh climate.

Purpose and Scope of Study

The study examines the potential cost, risk, and return characteristics of base metal supply with particular reference to northern and southern Canada. Our objectives are to:

- compare the quality and viability of base metal resources in the territories and provinces;
- explain comparative differences by more specifically analyzing time trends, the influence of geological regions and deposit types, and the return characteristics of economic discoveries;
- furnish a factual basis for assessing the direct effects of government mineral policies, and provide support for mineral policy formulation relating to infrastructure and northern development.

Conventional wisdom suggests that mineral exploration, development and production in remote areas is more costly and, therefore, less economic than in more favourably-located regions. We wish to examine this hypothesis with particular reference to base metal supply in the Canadian territories relative to the established mining areas of the provinces.

The study considers the economic consequences of the special geological features which underlie the base metal sector. Particular attention is given to:

- the exploration expenditures required for the discovery of an economic deposit;
- the variability of endowment characteristics among economic deposits;
- time trends in the cost-risk-return relationship which motivates investment.

Our methodology is based on data compiled for a large number of actual deposits over a relevant historical time period. Assessment of the economics of base metal supply is made by placing this experience in the context of present-day economic and technological conditions. In other words, if we were to begin to look today for the deposits which were in fact discovered during the historical period selected, how long would it take to discover them and which would be economic? What revenues and costs would be associated with the discovery, development, and production of the economic deposits? What effects would taxation payments have on the incentive to invest in mineral supply? In this way, we are using historical experience to project and plan for the future.

The analysis is carried out utilizing an extensive data base for the Canadian base metal sector which has been assembled and updated on a continuing basis at the Centre for Resource Studies since 1975. The information for the territories has been revised and updated for study purposes with respect to base metal exploration expenditure estimates, deposit-specific information for the actual discoveries included, and remoteness costs.[18] These additional data have been obtained from a wide range of published sources, private surveys, internal government reports, and confidential mining company studies.

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[18] The present work has evolved from two earlier studies.

B.W. Mackenzie, M.L. Bilodeau, L.J. Verleun, *Base Metal Potential North of 60: Economic Viability, Endowment Quality, Competitive Position*, report prepared under contract to the Department of Indian Affairs and Northern Development, Centre for Resource Studies, March 1984, 102 pp.

L.J. Verleun, *Base Metal Supply Potential in Northern and Southern Canada*, unpublished M.Sc. thesis, Queen's University, November 1984, 198 pp.

The study applies the information assembled to the economic evaluation of base metal supply in northern and southern Canada. Results are expressed in terms of various expected value and risk measures. These assessments are made on the following two bases:

- *potential value basis*, including all direct costs and revenues. This assessment represents what is potentially available prior to tax considerations, and reflects the fundamental value of base metal endowment;

- *after-tax basis*, considering the application of current Canadian taxation regimes to the overall potential values. This type of assessment addresses the question of incentive to the mining company deciding on investment in base metal exploration and development.

Organization of Study

A description of the study, its main findings, and policy implications are first presented in summary form.

Chapter 2 describes the evaluation procedure developed to assess and compare the quality and viability of base metal resources in northern and southern Canada. This provides terms of reference for assembling the data base, and for evaluating and explaining study findings.

The data base, presented in chapter 3, includes estimates of total exploration expenditures, a listing of possible economic discoveries for evaluation, projections of long-term metal prices, estimates of ore reserves and costs for individual deposits based on historical data, the development of generalized net smelter return conditions and deposit costing relationships, the specification of infrastructure assumptions, and estimates of remoteness costs.

Chapter 4 appraises the potential value of the base metal supply process in Canada for a set of "base case" conditions. This provides a standard for evaluating and comparing the economic potential of base metal supply in the territories and provinces.

The sensitivity of comparative north-south results to possible variations in metal price, cost of capital, the minimum size requirement, the mineral processing situation, and the annual exploration budget, is examined in chapter 5.

Time trends in the economics of base metal supply in the Canadian territories and provinces are evaluated in chapter 6. In chapter 7, comparative north-south assessments are made within each of the two major geological provinces: the shield and cordilleran regions. In so doing, inferences are drawn concerning the effect of other constituent regions.

A more detailed examination of the return characteristics associated with economic discoveries is carried out in chapter 8. The cash flow components are examined, comparative returns classified by deposit type are analyzed, and a more complete picture of time trends is taken by including base metal deposits discovered prior to 1946.

Chapter 9 examines the after-tax value of base metal supply. Current Canadian mining taxation systems are overlaid on the potential value assessments to assess the incentive for mining company investment and relative tax burdens in the territories and provinces.

The final chapter summarizes results and draws a number of conclusions from the study findings. Several matters mentioned in the text are presented in greater detail in the appendices. The inflation multiplier series applied is presented in appendix I. Appendix II describes the method of estimating base metal exploration expenditures. The possible economic discoveries evaluated are classified in appendix III by geological region and discovery date. Appendix IV examines time trends in base metal discovery methods. Finally, the Canadian taxation systems used to determine the after-tax value of base metal mining are outlined in appendix V.

2. APPRAISING THE POTENTIAL VALUE OF MINING: THE METHODOLOGY

The intent of this chapter is to describe the evaluation procedure used to assess and compare the quality and viability of base metal resources in northern and southern Canada. The concept of "the mineral supply process" which follows provides a framework for appraising the potential value of mining for this purpose.

The Mineral Supply Process

The mineral supply process consists of a series of activities by which minerals are converted from unknown geologic resources to marketable commodities. As portrayed in figure 1 and described below, the major phases of activity in the process are (1) exploration, (2) development, and (3) production. The basic stimuli of this process are the physical occurrence of mineral deposits in nature and the demand for mineral commodities in the economy. A positive response from both exploration geologists and market researchers to particular geologic and market factors combine to guide the selection of environments for exploration.

Mineral exploration, the first phase of mineral supply, is a sequential, information-gathering process consisting of two stages: primary exploration and delineation. During the primary exploration stage, potentially favourable areas of land are selected within an environment of interest and then are subjected to a series of geological, geophysical, and geochemical tests. Successful primary exploration results in the discovery of one or more mineral occurrences, although at this stage the ultimate size and value of any occurrence is unknown.

The mineral occurrences discovered provide justification for delineation, the second stage of exploration, during which information is assembled for estimating the size, grade, and physical characteristics of the discovery that are relevant to mineral or metal recovery. The objective of delineation is the identification of possible economic discoveries for evaluation. When the delineation stage has yielded enough information on a particular deposit, a decision is made about developing the deposit to production. If the characteristics of the delineated deposit warrant mine development, the mineral exploration phase is completed

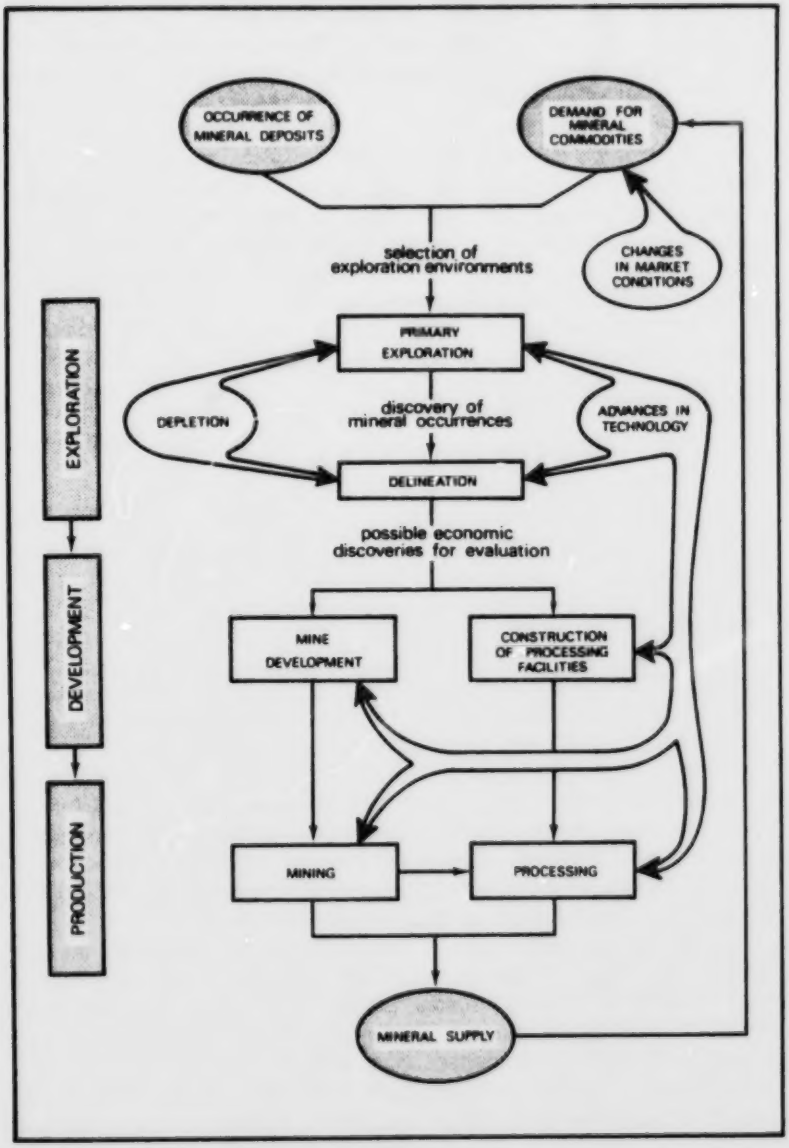

Figure 1. The Mineral Supply Process

with what is perceived to be an economic mineral deposit as its end result.

Development, the second phase of the mineral supply process, establishes productive mining and mineral processing capacity. Since processing is required to upgrade the mine product to a metal concentrate that can be transported and sold, the construction of processing facilities is carried out in conjunction with mine development. A mill may be installed at the minesite, or a common processing facility may be used to treat ores from a number of mines in a region.

When a mine has been developed and related processing facilities have been constructed, the third phase - production - commences. The mining stage of production may include stripping waste for open pits, preparing stopes (underground excavations for mining), developing ore reserves, drilling, blasting, transporting materials to the processing facilities, filling mined-out stopes, and associated technical and planning services. For base metal operations, the processing stage of production usually includes crushing, grinding, flotation, drying, disposal of tailings, and the loading of concentrate products for shipment. Through processing, the ore produced from a mine, which might contain 2 percent copper and 5 percent zinc, may be upgraded to produce a 25-percent copper concentrate and a 55-percent zinc concentrate, with the loss of 10 percent of the copper content and 20 percent of the zinc content in the tailings.

The end result of the mineral supply process in the context of this study is the production of concentrate at the minesite to satisfy market demand. Market demand conditions include product transportation and smelting and refining activities as well as the sale of the metal.

The mineral supply process is dynamic in several respects. First, the market demand for mineral commodities changes with time. The factors that account for changing demand include: variations in the requirements of end uses; changes in the properties and relative costs of substitute materials; development of new product markets; and modifications in transportation, smelting, and refining conditions. Second, the physical exhaustion of mineral deposits, or depletion, is inherent in their exploitation. Thus, continual exploration is required just to sustain the existing level of mineral production. Furthermore, exploration, guided by geologic concepts and skills, is a systematic process in the long term, tending to detect first those deposits that are largest, of highest grade, closest to the surface, or closest to markets. Consequently, such deposits should, on average, be discovered, developed, and exhausted

first, and deposits that are of lower grade, smaller, or harder to find come later. Thus, depletion causes the cost of mineral supply to rise over time. However, a third, offsetting dynamic force - advances in technology - is also at work. Such advances may include more efficient and extensive exploration techniques and improved mining and mineral-processing methods. This means, for example, that the best deposits are not necessarily found first, the Kidd Creek and Hemlo discoveries being notable Canadian examples. Advances in technology act to reduce the cost of mineral supply. The combined effect of these market, depletion, and technological forces determines the economics of mineral supply over time.

Potential Value of Mining

The potential value of mining is defined here as the difference between the revenues realized from mineral production and the costs required to realize those revenues, including an allowance for the cost of capital.[1] Since the cost of capital is deducted, this potential value represents the increase in real wealth that results from investing in mining rather than in some other economic activity. Thus, potential value reflects both the quality of mineral resource endowment and the viability of the mining sector. It also measures the productive capability of mineral resources and represents what is available for sharing between industry and government before mining taxation and other public policy considerations.

Methodology for Assessing the Potential Value of Mining

The potential value of mining is determined by the costs and revenues of the exploration, development, and production phases of the mineral supply process. The focal point of this process is economic mineral deposits. Consequently, potential value measures are derived from esti-

[1] The cost of capital is a real cost which affects the new wealth created by the mineral supply process.

mates of the exploration expenditures, development costs, and operating revenues and costs associated with an economic deposit.

In the evaluation procedure described here, the potential value of mining is appraised on the basis of historical experience. Two assumptions are necessary if the results are used to plan for the future. First, deposits yet to be found must resemble, in economic terms, those that have been found to date. Second, the cost of making a future discovery must be similar to the cost in the past. Since we know the mineral supply process is in fact dynamic, we endeavour to discern time trends within the overall historical experience.

The data base for assessing the potential value associated with an economic deposit comprises the documentation of actual exploration, development, and mining experience over a relevant historical timeframe - the 1946-77 period is used in the comparison of base metal potential in northern and southern Canada introduced in chapter 3. For useful forward planning, this information is then placed in the context of current outlook conditions.

In essence, the methodology (diagrammed in figure 2) follows these steps.

1. Total exploration expenditures are estimated for the historical time period of interest.

2. Significant deposits discovered as a result of these expenditures are classified by discovery date and listed for evaluation.

3. The cash flow characteristics of the development and production phases for each of these possible economic discoveries are evaluated on the basis of current outlook conditions.

4. Discoveries that, on evaluation, satisfy minimum conditions of size and profitability are considered to be economic deposits.

5. Cash flow characteristics of the development and production phases of all economic deposits are averaged.

6. Total exploration expenditures, which cannot in general be directly associated with the economic discoveries, are prorated across all economic deposits evaluated.

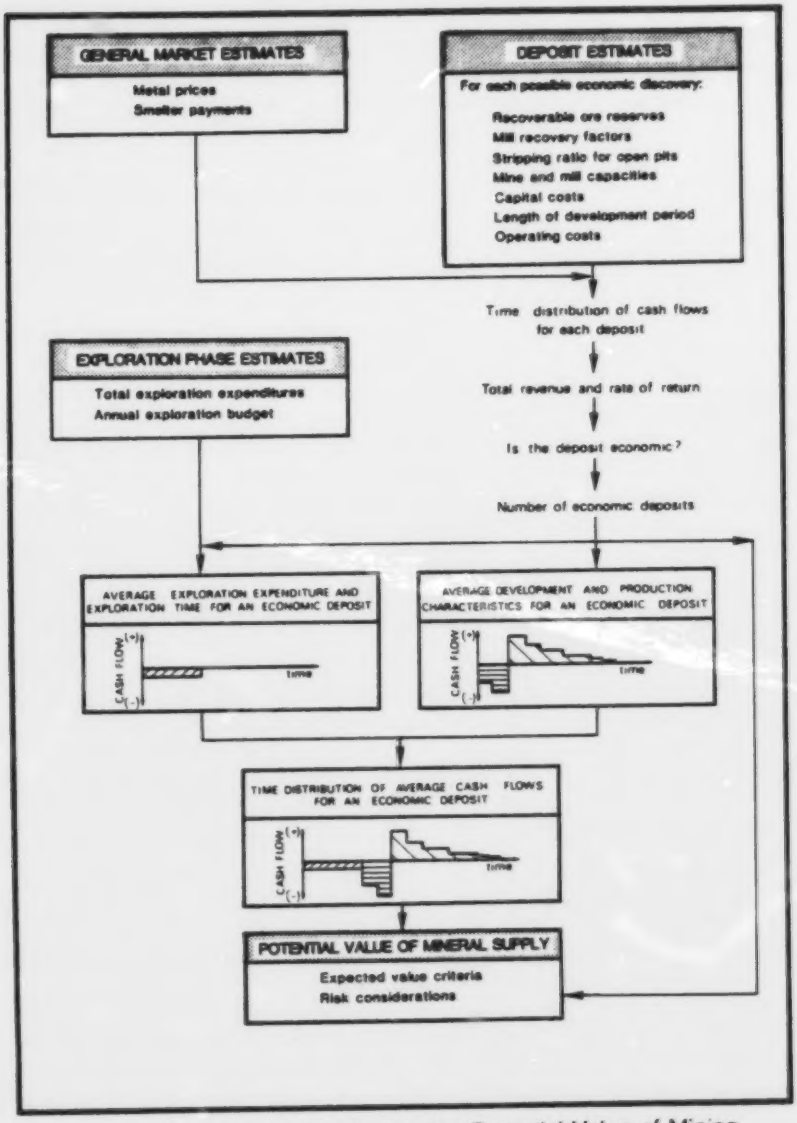

Figure 2. Procedure for Evaluating the Potential Value of Mining

7. The estimate for the exploration phase is integrated with the average characteristics for the development and production phases to portray the time distribution of average costs and revenues for an economic deposit from the start of exploration to the end of production.

8. Several expected value criteria and risk measures are derived from the assessment. These indicators reflect the potential value of mineral supply.

More specifically, the development and production phase characteristics for each of the possible economic discoveries (step 2 above) are evaluated (step 3), as shown in figure 2, by combining general market estimates of metal prices and smelter payments with estimates for individual deposits of the following: recoverable ore reserves; mill recovery factors; a stripping ratio for open pits; mine and mill capacities; capital costs, including the working capital requirement; the length of the preproduction development period; and operating costs. These estimates, based on the actual historical record, attempt to portray how each deposit would look today if it were awaiting development. A number of measures of economic worth are derived from the resulting cash flow distributions, including the total sales revenue generated and the rate of return. Those discoveries that satisfy minimum conditions for total revenue (size) and rate of return (profitability) are deemed to be economic (step 4). The cash flow estimates for all economic deposits are then averaged (step 5), resulting in a time distribution of average cash flows for the development and production phases of the mineral supply process.

With respect to appraisal of the exploration phase (step 6), the total exploration expenditure estimate (step 1) is divided by the number of economic deposits assessed (step 4) to determine the average exploration expenditure required to find and delineate an economic deposit. To evaluate the average exploration time that would be needed to make an economic discovery, the average exploration expenditure per economic discovery is divided by an assumed most-efficient annual exploration budget rate. These estimates for the exploration phase are then integrated with the appraisals for the development and production phases.

As portrayed in figure 2, the end result of this evaluation process is an assessment of the time distribution of average cash flows for an economic deposit over the three-phase mineral supply process (step 7). The expected value and risk measures which are derived from these estimates to portray the before-tax potential value characteristics of base

metal mining in the territories and provinces (step 8) are outlined in the following sections. As part of the evaluation, the sensitivity of results to key assumptions can be examined.

Expected Value Criteria

Expected value measures the average value that mining yields in the long term, when the successes and failures associated with a very large (theoretically infinite) number of discoveries are considered. The expected value of mining is derived from the time distribution of average cash flows for the discovery of an economic mineral deposit. This distribution is initially evaluated on a potential value basis as portrayed in figure 2. Then, to provide indicators of investment incentive from the mining company's viewpoint, and measures of government revenues, the potential value assessment is converted to an after-tax basis. The mining company decides on an after-tax basis whether it is worthwhile to invest in exploration and development. Because of time value considerations, the average cash flow characteristics must be brought to a common point in time or spread evenly over a common period of time to make a valid assessment. The following two measures of expected value - expected value per economic discovery and expected rate of return - are applied in this study.

1. Expected Value per Economic Discovery

An exploration expenditure E is required on average for the discovery and delineation of an economic deposit, yielding an average return R.

Thus:

$$EV = R - E$$

where EV = expected value per economic discovery;
R = average net return from development and production associated with the discovery of an economic mineral deposit;
E = average exploration cost required to find and delineate an economic deposit.

To make a valid comparison, R and E are expressed as time-adjusted values at the start of the exploration phase, using a cost-of-capital estimate for investment funds as the discount rate.

The higher the EV assessment, the more attractive exploration is perceived to be in the long term. Usually an expected value per economic discovery greater than zero is regarded as a necessary condition for investment. A negative EV signifies that exploration is an unacceptable investment in the long term, with more money going "into the ground" in time-adjusted terms than coming out.

The expected value per economic discovery is analogous to the criterion of net present value generally used in evaluation practice. As such, EV reflects the intrinsic economic value of mineral supply. EV comprises both size and profitability components of investment.

2. Expected Rate of Return

The expected discounted cash flow rate of return on investment can also be evaluated based on the time distribution of average cash flows for an economic deposit, as depicted in figure 2. By definition, rate of return is the discount rate that equates the present value of the positive cash flows with the present value of the investment. In economic terms, rate of return is the average percentage annual return that exploration is estimated to yield over the life of the three-phase mineral supply cycle. Using this method, the minimum acceptable condition for investment in the long term is an expected rate of return equal to the cost of capital.

Expected values are assessed in this study on the basis of overall mining activity and reflect the average performance of all organizations that have undertaken investment. Obviously, there are benefits to be gained from the application of superior skills and selectivity. In geologic environments characterized by unacceptable overall expected values, the selection of opportunities of above-average merit is a necessary condition for long-term success. This can only result from the application of superior skills, developed within a mining company over time through continuing education in particular environments of interest.

In seeking explanations for differences in overall expected value results, the two main components - exploration expenditures, and the returns associated with the discovery of economic deposits - are given the following more detailed examinations.

Exploration Expenditures

Time trends in exploration expenditures reflect the interplay of four dynamic elements:

- changing rate of discovery for economic deposits;
- depletion effects in terms of increasing exploration difficulty;
- real changes in the costs of labour and interindustry inputs to exploration;
- advances in geological concepts and exploration technology in terms of lower discovery costs.

In this study, the exploration expenditure component of expected value is assessed by the following indicators:

- average undiscounted exploration expenditure per economic discovery;
- average exploration period required to find and delineate an economic deposit;
- average exploration expenditure per economic discovery expressed as a discounted value at the start of exploration. E.

Returns from Economic Discoveries

According to the evaluation procedure adopted, the returns associated with economic deposits reflect the quality of the mineral resources discovered. Time trends in the quality of mineral resources available for mining are the resultant of two dynamic elements:

- depletion effects in terms of lower-quality economic discoveries;
- advances in geologic concepts and exploration technology which enable previously undetectable high-quality deposits to be found.

The quality of mineral resources has a number of facets, including:

- deposit size;
- geological grade;
- geographic location;
- ore width;
- depth below surface;

- mineralogical complexity;
- geotechnical properties.

Deposit quality affects the selection of mining and processing methods, recoverable ore reserves, mineral processing recoveries, stripping ratio, scale of operations, sales revenues, and capital and operating costs. Thus, the quality of mineral resources is a critical ingredient of the potential value of mining.

The quality of mineral resources discovered is examined in the study using the following average value characteristics:

- return from development and production for an economic deposit expressed as a discounted value at the start of development;
- rate of return for an economic deposit based on the time distribution of average cash flows from development and production;
- size of an economic deposit in terms of ore reserve tonnage;
- metal product mix realized from an economic deposit;
- step-by-step assessment of the undiscounted development and production phase components of the unit cash flow from economic deposits.

The last of these indicators - the components of unit cash flow - is intended to reveal specific facets of mineral resource quality. The step-by-step procedure, outlined in table 1, expresses results in dollars per tonne of ore produced from economic discoveries.

Gross in-situ value, the product of geological grades and metal prices, reflects the expected geological grade. *Mining losses* account for the part of geological reserves which is inevitably left behind in pillars and remnants. Also, geological grades are diluted by the mining of barren or low-grade waste rock adjacent to the deposit itself. These mining losses are a function of such facets of deposit quality as deposit size, ore width, depth below surface, and geotechnical properties.

Milling losses measure the incomplete recovery of the metal content of the mill feed in the concentrate product. For example, in the upgrading of a copper-zinc ore to separate copper and zinc concentrate products, 10 percent of the copper content and 20 percent of the zinc content may be lost in the tailings. Milling losses depend in part on the mineralogical characteristics of the deposit.

In determining the value of the concentrate products, *smelting and refining charges* have to be deducted. The combined effect of these charges on revenue received by the mining operation may be illustrated

Table 1

AVERAGE DEVELOPMENT AND PRODUCTION PHASE COMPONENTS OF CASH FLOW FROM ECONOMIC DEPOSITS ($ per tonne of ore)

Gross In-Situ Value	
Less:	Mining Losses
	Milling Losses
	Smelting and Refining Charges
	Concentrate Transportation Costs
Revenue at the Minesite	
Less:	Preproduction Capital Expenditures
	Production Costs
Before-Tax Cash Flow	

by expressing the net value of metal contained in the concentrate (after deducting smelting and refining costs) as a percentage of the refined metal price. Thus, the revenue received for copper in concentrate form can represent 70 percent of the copper price, while 50 percent of the zinc price may be paid for zinc contained in a zinc concentrate. Typically, gold and silver byproducts contained in base metal concentrates realize in the order of 90 percent of their refined prices. Smelting and refining charges are not only a function of the mix of metals recovered. They also depend on the grades of concentrate produced and on refined metal prices.

Concentrate transportation costs then have to be deducted, as shown in table 1, to work the valuation back to an estimate of revenue at the minesite. Transportation costs depend on the geographic location of a deposit in relation to the smelting facilities.

Revenue at the minesite normally represents the top line of a cash flow calculation associated with the contemplated development of a mineral deposit. The costs associated with producing the concentrate then have to be deducted, including the *preproduction capital expenditures* required to develop the necessary capacity and the *production costs* incurred in operating the mine. These costs are a function of virtually all facets of the quality of the mineral resource input.

The year-by-year deduction of capital and operating cost estimates from revenue at the minesite results in a time distribution of potential or *before-tax cash flows*. The cash flow distribution is then combined with an estimated cost of capital to derive more succinct measures of the return characteristics of economic deposits.

Risk Considerations

Four types of risk are associated with realizing the expected value offered by the mineral supply process.

1. *Market risk*, reflecting the sensitivity of mining economics to the uncertainties associated with forecasts of short-term fluctuations and long-term trends in mineral commodity prices, including exchange rate uncertainty.

2. *Project risk*, caused by the uncertainty associated with estimating ore reserves, recovery and dilution factors, capital expenditures, and operating costs for specific economic deposits.

3. *Geologic risk*, related to the uncertainty of the return, given an economic discovery, which arises because of the high degree of variability in size, grade, and other geologic parameters among economic deposits.

4. *Discovery risk*, the low probability - typically a 1 to 2 percent chance - of an economic mineral deposit, given the discovery of a mineral occurrence.[2] The implications of discovery risk for exploration planning are of particular importance.

These risks, individually and collectively, present challenges to the long-term profit, survival, and growth of mining organizations. Inevitably, ac-

[2] The discovery of a mineral occurrence or, in other words, a technical or geologic success, as portrayed in figure 1, is the successful outcome of primary exploration. More specifically, the discovery of a mineral occurrence can be defined as indications of mineralization of potentially economic grades across mineable widths obtained by drilling. Adopting this definition, empirical studies of mineral exploration in Canada and Australia show that there is typically a .01 to .02 probability of discovering an economic deposit each time a mineral occurrence is found.

tual results are very much different than those indicated on the basis of expected values. These risks need to be considered in the formulation of government mineral policies.

The market risk arises from uncertainties in the materials market for mineral commodities. The economics of mineral supply is sensitive to anticipated prices. Flexibility is required in policy and planning to contend with unexpected changes in market conditions. Thus, the comparisons made in the present study of mining potential in northern and southern Canada consider a wide range of long-term metal price projections.

The project risk associated with the estimation of ore reserves, mining and processing costs for a particular mineral deposit is critical when an investment decision is being taken concerning mine development. When generalizing across many deposit situations to appraise the economics of mineral supply for broad regions of interest, however, as we are doing here, the individual project risks are less vital.

The geologic risk may be measured by cumulative probability distributions of such parameters as total revenue, rate of return, and net present value for all economic discoveries. With reference to figure 3, cumulative probability distributions are constructed in the following manner. For each return parameter, individual deposit values are ordered from lowest to highest. These values are then plotted against cumulative probability, the fraction of the total number of economic deposits which has values less than or equal to each value. When the highest value is reached, the cumulative probability is unity. Key statistics may then be derived from this distribution, as shown, to characterize the variability of the parameter. For example, a cumulative probability of .10 specifies the lower-decile value, i.e. 10 percent of the economic deposits have values less than or equal to the lower decile and 90 percent have higher values. The median (or middle) deposit value is defined by the .50 cumulative probability. The mean deposit value is the average of all deposit values. The distribution of returns around this mean value reflects the geologic variability which exists among deposits.

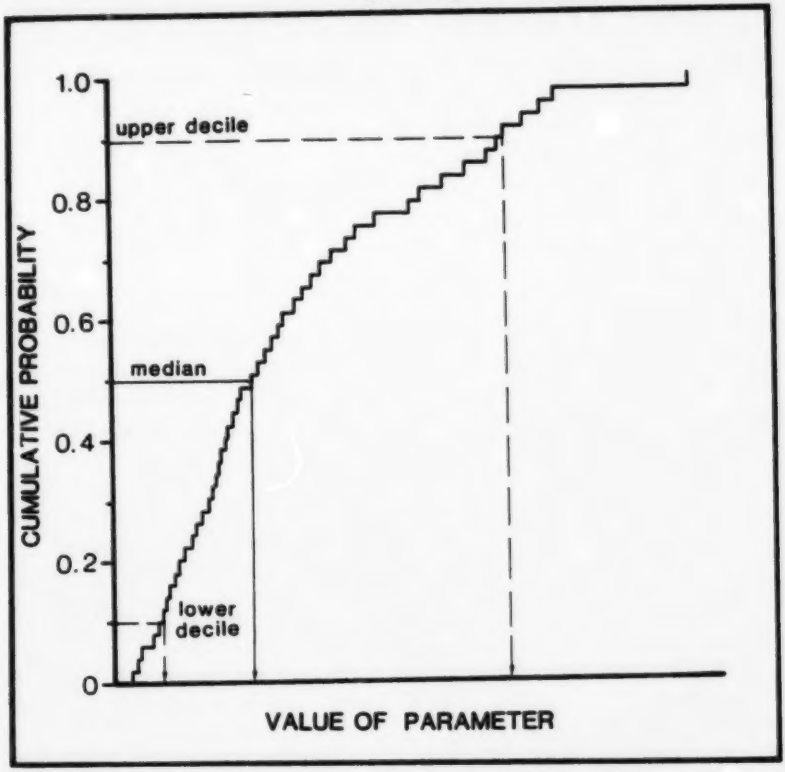

Figure 3. Cumulative Probability Distribution and Key Statistics of a Return Parameter for Economic Deposits

Because the discovery risk is so high, the application of limited exploration funds does not ensure the realization of expected values, and exploration resources are often expended without success. The organizational risk associated with exploration success can be quantified by applying the classical problem of the gambler's ruin.[3] The practical consequence of discovery risk for a mining company is that there is a

[3] The problem of the gambler's ruin in probability theory concerns a gambler with limited capital who wagers against a "house" with essentially unlimited resources. The gambler is ruined and the game terminates if at any point his or her capital balance falls to zero. For any specified set of conditions, the problem is to determine the probability that the gambler will be ruined.

large difference between the average exploration cost required to find and delineate an economic deposit and the exploration funds required to ensure success. For example, the exploration funds required to be 90 percent sure of making at least one economic discovery are 2.3 times the average exploration cost associated with an economic discovery.

Summing Up

Assessments of the potential value of the mineral supply process are derived from estimates of the exploration expenditures, development costs, and operating revenues and costs associated with an economic deposit. The evaluation procedure adopted places deposit-specific historical experience in the context of current outlook conditions. Expected value criteria measure the long-term viability of mineral supply. In seeking explanations for overall comparative results in the territories and provinces, the two main components of expected value - exploration expenditures, and the returns associated with the discovery of economic deposits - are subjected to more detailed examination. Four types of risk - market, project, geologic and discovery - are associated with realizing the expected value of mineral supply.

3. BASE METAL SUPPLY IN NORTHERN AND SOUTHERN CANADA: THE DATA BASE

The data base assembled to assess and compare the economics of mineral supply in northern and southern Canada is described in this chapter.

Study Specifications

Base metal resources, as defined in this study, include copper, zinc, lead, and molybdenum deposits together with any associated gold and silver content.

The potential value of base metal supply is initially evaluated for Canada overall, providing a standard of comparison for more specific assessments in the territories and provinces. These appraisals of exploration costs and returns consider all significant base metal deposits discovered during the 32-year period 1946-77. A comparison is also made of the return characteristics of pre-1946 discoveries with those of deposits found during the 1946-77 period.

Time trends are further analyzed by subdividing the 1946-77 period into three intervals: 1946-61, 1962-69, and 1970-77. As outlined in chapter 2, the analysis of time trends is intended to show the combined effect of depletion, and advances in geological concepts and exploration technology. Although the time intervals selected are somewhat arbitrary, the choice reflects a compromise between two factors. First, the intervals should be as short as possible to provide a sufficient number of time series results within the overall study period. Second, each interval must be long enough to include a meaningful sample size of exploration and discovery experience. The limited amount of mineral exploration in northern Canada during the earlier part of the study period necessitated the selection of an initial 16-year time interval, followed by two 8-year intervals.

The territories and provinces have different mixtures of geological regions. Thus, to help explain overall economic differences, more specific comparisons are made within the two major geological provinces, the shield and cordilleran regions.

Money values are expressed in constant 1983 dollars.[1] The Canadian gross national expenditure implicit price (GNEIP) index is used to inflate historical data to 1983-dollar equivalents. This index provides a good approximation of the actual cost inflation associated with base metal mining over the study period. The GNEIP index for 1946-77 and the inflation multiplier series derived from it are tabulated in appendix I.

Since money values are expressed in constant dollars, all discount rates and costs of capital are therefore expressed as "real" (as opposed to nominal) rates. Inflation is taken into account in order to assess tax allowances and payments correctly.

A key aspect of our evaluation is to determine which of the historical discoveries would be economic under today's conditions. An economic deposit is defined as a discovery realizing a total revenue of at least $20 million and a rate of return of at least 8 percent. The purpose of the $20-million size cutoff is to keep the data base manageable while insuring that any deposit of significance is included in the evaluation.[2] The 8-percent rate-of-return investment margin has been selected as our best estimate of the weighted average cost of capital.[3] The effects of size

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1 Canadian dollars, unless otherwise stated.

As the purchasing power of money varies from year to year, depending on the rate of inflation, it is necessary to define the value of money with respect to time. It is appropriate to assess the economics of mineral supply in constant money terms. This means that the purchasing power of money units, measured by what they will buy, is constant. For this purpose, money units are defined with respect to purchasing power at a particular point in time (e.g. 1983). This is done to standardize estimates and results.

An inflation multiplier of 1.14 can be used to convert the study estimates and results from 1983 to 1987 Canadian dollar equivalents.

2 The size of a deposit can be measured in a number of ways. Ore reserve tonnage and recoverable metal content are two indicators that neglect grades and prices on the one hand, and prices on the other. Such criteria as cash flow and net present value combine size and profitability considerations. The measure of deposit size used throughout this study is total revenue over the life of the mine (i.e. net smelter return price times recoverable metal content valued at the minesite). Total revenue provides an economic measure of deposit size as distinct from profitability.

The $20-million minimum size cutoff effectively includes in our data base all deposits of at least 200,000 tonnes that offer medium term potential for development.

3 The weighted average cost of capital in constant money terms comprises the costs of individual sources of funds, which can be simply grouped into

cutoffs of $100 million and $250 million, and profitability thresholds of 5 percent and 15 percent on comparative economic results for northern and southern Canada are also examined.

The Exploration Phase

Exploration Expenditures

Estimates of total base metal exploration expenditures are required for Canada, the territories, and the provinces, classified by each time interval and geological region of interest. The intention is to include all costs associated with searching for and delineating the possible economic discoveries including, of course, all unsuccessful exploration expenditures.

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two types - debt and equity.

The cost of debt capital is an explicit interest cost, nominated in current money terms, that must be corrected for inflation. The constant money cost of debt funds is illustrated by the 3-percent average historical interest rate which has prevailed in bond markets. This real cost varies with time, especially when the general rate of inflation increases or decreases unexpectedly. If interest payments are deductible for tax purposes, as they are for corporate income tax in Canada, the after-tax cost of debt funds must be reduced accordingly.

The cost of equity funds is an implicit opportunity cost that can be estimated empirically. For example, R. Ball evaluated a cost of equity capital for Northern Mining Corporation, an Australian company primarily concerned with diamond-mining opportunities. He estimated a most-likely constant money cost of capital for the company's equity of 6.8 percent within a possible range of 5.2 percent to 9.9 percent. Source: "Northern Mining Corporation NL: Estimate of a Discount Rate for Valuing Equity"; Ray Ball, Australian Graduate School of Management, August 1981, unpublished.

In summary, considering inflation and taxation effects, debt capital represents a low-cost source of funds, with constant money after-tax costs typically in the range of 1 to 3 percent. The cost of equity funds typically varies from 6 to 15 percent. The financial structure of a mining company - basically how much debt and how much equity it utilizes - is applied to cost estimates for the individual sources to assess the weighted average cost of capital. The 8-percent weighted average cost of capital assumed in this study should be viewed in this context.

Base metal exploration expenditures are difficult to estimate because Statistics Canada data are in too aggregate a form to be directly applicable. An outline of the sources of data and method used to derive the study estimates is given in appendix II. In summary, base metal exploration expenditures are derived from annual Statistics Canada data for metallic mineral exploration expenditures by province and territory. Allowances for the costs of searching for and delineating metallic mineral deposits excluded from our study - notably nickel, uranium, gold, silver, tin-tungsten, and iron ore deposits - are deducted from the metallic mineral totals. This approach, combining objective data and subjective judgment, should provide a meaningful order-of-magnitude assessment of base metal exploration levels.

The total exploration expenditures associated with searching for and delineating the base metal deposits discovered during the study period are summarized in table 2 by time interval. Of the total base metal exploration expenditure of $3.4 billion, only 10 percent was invested in the north, even though the Yukon and Northwest Territories comprise 40 percent of the total Canadian landmass. The northern share, however, increased from 4 percent during the 1946-61 interval to 17 percent in the 1970-77 interval.

Table 2

TOTAL BASE METAL EXPLORATION EXPENDITURES BY TIME INTERVAL ($ 1983 million)

	Time Interval			
Region	1946-61	1962-69	1970-77	1946-77 Period
Canada	1,044	1,207	1,129	3,380
The territories	40	110	187	337
The provinces	1,004	1,097	942	3,043

Base metal exploration expenditures are also categorized by geological region as presented in table 3. About 50 percent of the Canadian total has been expended in the shield, 35 percent in the cordilleran region, with the remaining 15 percent invested elsewhere. The mixture is shown to be quite different, however, in northern and southern Canada. In the territories, for example, almost 60 percent of the

base metal exploration has been carried out in the cordilleran region, only 29 percent in the shield, and 11 percent in other regions. It is also clear from the tabulation that the shield and cordilleran regions are of central importance to the north-south comparison being made in this study, together accounting for 85 percent of Canada-wide expenditures.

Table 3

TOTAL BASE METAL EXPLORATION EXPENDITURES BY GEOLOGICAL REGION ($ 1983 million)

	Geological Region			
Region	Shield	Cordilleran	Other	Total
Canada	1,639	1,229	512	3,380
The territories	99	202	36	337
The provinces	1,540	1,027	476	3,043

Annual Exploration Budget Rate

Based on discussions with exploration personnel and on observations of both successful and unsuccessful exploration at work, a $4-million annual exploration budget has been chosen as an efficient level for an exploration organization. While opinions on this subject vary and the $4 million figure may be contested, there is little doubt that the most efficient budget rate lies within the range of $2 to $6 million per year.

The $4-million budget is considered large enough to afford the best possible exploration skills and techniques, and small enough to encourage a high degree of motivation and organizational efficiency. Assessments are also carried out for annual exploration budgets of $2 million and $6 million.[4] Total exploration expenditures are not changed by these

[4] A group of five to eight geologists - "hunting band" size - with an annual budget of $2 million to $6 million appears to be the most efficient and effective, retaining the characteristics of an entrepreneurial organization, while avoiding the weaknesses of a bureaucracy. P.A. Bailly (1977) analyzed the relationship between exploration expenditures and the number of economic deposits discovered as a function of exploration budget size, focusing on metallic mineral exploration in Canada during the 1958-73 period. His results, converted here to 1983 Canadian dollars, show that the

budget rate variants. All that is affected is the estimated average time required for an exploration organization to discover an economic deposit.

Possible Economic Discoveries for Evaluation

A total of 291 base metal deposits discovered to 1977 which could possibly satisfy economic deposit conditions are selected for evaluation. These deposits are listed in alphabetical order in appendix III, classified by geographic area, discovery date, geological region, and deposit type.

The distribution of the possible economic discoveries by discovery date is summarized in table 4. The intention has been to include all known deposits of at least 200,000 tonnes which offer medium-term potential for development. A discovery is considered to be made in the year when the deposit which ultimately forms the basis for mine development is first encountered by drilling. Deposits are treated

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$2 to $10 million budget range is much more efficient than larger or smaller sizes. "Changing Rates of Success in Metallic Exploration", P.A. Bailly, paper presented at Geological Association of Canada annual meeting, Vancouver, April 1977.

Annual Exploration Budget	Percentage of Exploration Expenditures	Percentage of Economic Discoveries
> $10 million	44	15
$4 - 10 million	14	35
$2 - 4 million	13	40
< $ 2 million	29	10

If its exploration budget is too small, the exploration organization cannot mount a modern, efficient, and competitive program. At the other extreme, companies with larger budgets typically develop organizations where procedures become formalized and bureaucratic styles develop. The inefficiency of organizations with the larger budgets is clearly shown in Bailly's results.

A dilemma arises when a mining company wishes to invest larger amounts in exploration yet remain efficient. This problem can be resolved by dividing exploration activity into a number of decentralized semi-autonomous units which are able to maintain the favourable organizational characteristics with a competitive budget and staff size. These units should be given strategic guidelines by a central corporate group that also provides specialized, high quality support, and the financial backing to sustain exploration activities.

individually if their discovery required essentially independent primary exploration programs.

Table 4

NUMBER OF POSSIBLE ECONOMIC DEPOSITS BY DISCOVERY DATE

	Discovery Date					
Region	Pre-1946	1946-61	1962-69	1970-77	1946-77 Period	Total
Canada	62	93	72	64	229	291
The territories	1	11	27	18	56	57
The provinces	61	82	45	46	173	234

Of the total number of deposits, 229 were discovered during the 1946-77 study period. While the 62 pre-1946 discoveries cannot be included in our overall analysis of economic potential because there is no exploration expenditure data prior to 1946, they play a role in providing a more complete picture of the quality of base metal resources and the time trend of returns from economic deposits.

As shown in table 4, 20 percent of the discoveries have been made in northern Canada, an area previously shown to have accounted for 10 percent of Canadian base metal exploration expenditures. The territories' share of discoveries increased from 12 percent during the 1946-61 interval to 38 percent in 1962-69, before falling off to 28 percent in the 1970-77 interval (as compared to an increase from 4 percent to 17 percent of Canada-wide exploration expenditures).

The possible economic discoveries are classified by geological region in table 5. About 12 percent of the discoveries in the shield and 31 percent of the deposits found in the cordilleran region are situated in the territories. All of the platform region deposits have been discovered in the north, while the discoveries in the appalachian region all occur in the provinces.

Table 5

NUMBER OF POSSIBLE ECONOMIC DEPOSITS BY GEOLOGICAL REGION

	Geological Region				
Region	Shield	Cordilleran	Appalachian	Platform	Total
Canada	146	96	39	10	291
The territories	17	30	-	10	57
The provinces	129	66	39	-	234

Table 6 subdivides the possible economic deposits into the three main base metal deposit types - volcanic-associated, sediment-hosted, and porphyry. While this breakdown cannot be used for the overall evaluation of the potential value of base metal mining, we will later find it of assistance in explaining comparative return characteristics for economic deposits in the territories and provinces.

Table 6

NUMBER OF POSSIBLE ECONOMIC DEPOSITS BY DEPOSIT TYPE

	Deposit Type				
Region	Volcanic Associated	Sediment Hosted	Porphyry	Other	Total
Canada	152	44	31	64	291
The territories	13	26	3	15	57
The provinces	139	18	28	49	234

As shown in table 6, volcanic-associated deposits predominate in the provinces, accounting for 60 percent of total discoveries. On the other hand, about 46 percent of the possible economic deposits discovered in the north are of the sediment-hosted type.

Mineral Market Conditions

General market estimates are made to evaluate the time distribution of revenues for each of the possible economic discoveries.

Metal price is both the most important and the most uncertain variable in the assessment of cash flows. For this reason, cash flows are evaluated as a function of price. While the main part of our appraisal is based on a single-point set of expected prices, the sensitivity of comparative north-south results to lower-limit and upper-limit price levels is also examined. Table 7 shows the prices used.[5]

Table 7

LONG-TERM METAL PRICE PROJECTIONS (U.S. dollars)

Metal	Price Basis	Lower Limit Prices	Expected Prices	Upper Limit Prices
Copper	per pound	0.85	1.05	1.30
Gold	per ounce	400.00	550.00	800.00
Lead	per pound	0.25	0.35	0.45
Molybdenum	per pound in concentrate	4.50	6.00	10.00
Silver	per ounce	10.00	13.00	20.00
Zinc	per pound	0.45	0.60	0.70
Exchange rate	U.S.$/C$	0.95	0.80	0.70

These estimates are long-term average price projections, the period of which is intended to correspond to the timeframe of the three-phase mineral supply process being evaluated. Since the prices are only applied in the final production phase, the relevant time period extends from about 10 years to 50 years into the future.

The price estimates presented in table 7 and used in the study may be considered optimistic in terms of 1986-87 price levels and in terms of current market projections which tend to be correlated with experience

[5] The United States dollar price projections have been combined with exchange rate estimates so as to give the widest possible Canadian dollar price range. The correlation between metal prices and the exchange rate has not been considered. This correlation would have the effect of increasing the U.S.$/C$ exchange rate as a function of metal prices.

in the 1980s. However, there will in fact be little relationship between prices 10 to 50 years hence and currently prevailing conditions.[6]

In this study, it is the comparative differences in mining potential in northern and southern Canada, not the absolute economic values, which are of prime interest. Thus, the long-term metal price projections, held constant in each case, are not so critical. However, since the relative north-south appraisal may be a function of the level of market prices, comparative differences are examined for a wide range of possible future prices.

The assessment of costs and revenues assumes that metallic mineral concentrate is produced at each possible mine. General net smelter return conditions for copper, lead and zinc concentrates are used to convert the forecast metal prices to a revenue estimate for the sale of concentrate at the smelter.[7] The general form of the smelter payment applied is as follows:

$$NSV = \frac{(M - D)(P - r)}{100} - \left[T + t(P - Pv)\right] + C$$

where: NSV = net smelter value per tonne of concentrate at the smelter;
M = grade of concentrate;
D = unit deduction, percent;

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6 Average metal prices, expressed in constant money units, have been remarkably constant over the past century. See, for example, "Historical Mineral Production and Price Trends", U. Petersen and R.S. Maxwell, *Mining Engineering*, January 1979, pp. 25-34. Consequently, the 1980s depression in metal prices, while exceptionally prolonged, is viewed as being mainly temporary in nature. While "structural change" advocates would not agree, the projections adopted here assume prices will in time rise to their historic levels.

7 The net smelter conditions for copper, lead and zinc concentrates are based on a worldwide survey and analysis of approximately 200 actual smelter contracts by Lewis and Streets. See: P.J. Lewis and C.G. Streets, "An Analysis of Base-Metal Smelter Terms", in the *Proceedings of the Eleventh Commonwealth Mining and Metallurgical Congress*, Hong Kong, 1978. Institution of Mining and Metallurgy, London. A number of modifications have been made based on discussions with marketing personnel to update the general findings of Lewis and Streets and adapt them to more specific Canadian conditions.

P = metal price, $/tonne;
r = refining charge, $/tonne of metal;
T = treatment charge, $/tonne of concentrate;
t = treatment charge price adjustment;
Pv = base value metal price, $/tonne;
C = credits for other metals contained, $/tonne of concentrate.

As shown by the relationship, the payment received depends on the grade of concentrate produced (M), the metal price prevailing in the market at the time of sale (P), and the credits realized for other payable metals in the concentrate, particularly gold and silver byproducts (C). Deductions are made by the smelter to allow for the cost of processing the concentrate to a refined metal product and for a profit margin. These deductions include a unit deduction for metallurgical losses (D), a refining charge (r), and a treatment charge that allows for smelting costs (T). The treatment charge may be adjusted as shown depending on the relationship between the metal price at the time of sale (P) and a base price specified in the contract (Pv). Possible penalties for contaminant metals (mercury and arsenic, for example) contained in the concentrate are neglected. All concentrate values are expressed on a dry tonne basis. Concentrate transportation charges are then deducted from the net smelter value to work the payment back to a minesite revenue.

Individual Deposit Estimates

Deposit-specific estimates of recoverable ore reserves, mine and mill capacities, a stripping ratio for open pits, the length of the preproduction period, preproduction capital cost including the working capital requirement, the cost of major modifications, sustaining capital, operating cost, mill recovery factors, concentrate grades, and concentrate transportation, are calculated for each of the 291 possible economic discoveries, based on present-day economic and technological conditions. These deposit estimates utilize actual historical data and feasibility study estimates to the extent available. Otherwise, generalized Canadian

costing relationships are applied, reflecting an order-of-magnitude level of accuracy.[8]

The form in which the basic estimates are provided for each deposit is shown in figure 4. The coding scheme maintains the anonymity of the deposits and facilitates their classification for analysis. Coding specifies the following characteristics of the deposit:

1 geological region
2 province
3 deposit code
4,5,6 geological classifications
7 mining method
8 underground stoping method
9 type of discoverer
10 acquisition variant
11 ore type
12 base metal ore type
13 investment tax credit

The first sheet of deposit estimates (figure 4) and the top of the second sheet (to the dotted line) itemize the information which must be specified to evaluate a deposit on the basis of the generalized costing relationships. Estimates based on actual deposit data and feasibility study projections are given below the dotted line on the second sheet.

The generalized deposit costing relationships used in the appraisal when actual data are not available, provide an order-of-magnitude (± 30 percent) level of accuracy. These relationships are outlined as follows:

[8] For examples of this type of generalized deposit costing procedure, see T.A. O'Hara, "Quick Guides to the Evaluation of Orebodies", *CIM Bulletin*, February 1980, pp. 87-99; A.L. Mular, *Mining and Mineral Processing Equipment Costs and Preliminary Capital Cost Estimation*, special volume 25, The Canadian Institute of Mining and Metallurgy, 1982, 265 pp.; B.W. Mackenzie, "Generalized Deposit Costing Relationships", pp. 438-458 in *Economic Guidelines for Exploration Planning*, course notes, Department of Geological Sciences, Queen's University, 1985, 608 pp.

DEPOSIT INFORMATION FORM - CANADA

DEPOSIT CODE: 1 2 3 4 5 6 7 8 9 10 11 12 13

DISCOVERY DATE:

GEOLOGICAL RESERVES:
1.
2.
3.

MINING METHOD:

RECOVERABLE RESERVES:
1.
2.
3.

PREPRODUCTION STRIPPING (m^3):
UNCONSOLIDATED OVERBURDEN.....
WASTE ROCK.....

AVERAGE STRIPPING RATIO (W:O):

AVERAGE ORE WIDTH (M):

SHAFT DEPTH (M):

MAJOR MODIFICATIONS:

ROADS (KM):

FLY-IN PROGRAM (YES/NO): DISTANCE (KM):

ACCOMMODATIONS (% OF EMPLOYEES):
HOUSES.....
PERMANENT BUNKHOUSE FACILITIES.....

AMENITIES (% OF EMPLOYEES):
TOWNSITE.....
CAMPSITE.....

TYPE OF POWER FACILITY (UTILITY/DIESEL):

TRANSMISSION DISTANCE IF UTILITY (KM):

Figure 4. Deposit Estimate Form

REGIONAL MILL ALTERNATIVE:
Capacity (tonnes per year).....
Ore transport distance (km).....
Roads required (km).....

CONCENTRATE TRANSPORTATION:

Commodity				
Destination				
Road distance (km)				
Rail distance (km)				
Ocean route				

ACTUAL INFORMATION

ORE CAPACITY (TONNES PER YEAR):

MINE RECOVERY (%):

MINE DILUTION (%):

AVERAGE ORE WIDTH (m):

PREPRODUCTION PERIOD (YEARS):

PREPRODUCTION CAPITAL COSTS ($ MILLION OR % CHANGE):

		Infrastructure Breakdown	
Mine development		Roads	
Mine plant and equipment		Housing	
Mill facilities		Townsite	
Infrastructure		Power	
Working capital			
Total		Total	

OPERATING COSTS ($ PER TONNE OF ORE OR % CHANGE):

Mining	
Milling	
Overheads	
Total	

METALLURGICAL RECOVERIES (%):

CONCENTRATE GRADES (%):

REGIONAL MILL ALTERNATIVE:
Capital cost ($ million).....
Operating cost ($ per tonne of ore).....

Figure 4. (continued)

- concentrate transportation cost as a function of road, rail, and ocean modes of shipment, transportation distance, and the number of transfer points;
- mine and mill ore capacity for open pit and underground mines as a function of recoverable ore reserves;
- preproduction stripping cost for open pits as a function of unconsolidated overburden and waste rock volumes;
- capital cost of open pit equipment and maintenance facilities, open pit operating cost, and open pit sustaining capital cost as functions of the annual tonnage of ore and waste material removed;
- capital costs of shaft sinking, declines, shaft equipping and associated surface installations as functions of depth and mine capacity;
- mine development capital cost as a function of mine capacity and average ore width;
- capital cost of underground mine plant and equipment and underground sustaining capital requirement as functions of mine capacity;
- underground mine operating cost as a function of mine capacity and mining method;
- mill capital and operating costs as functions of mill capacity and ore types;
- administrative and overhead operating cost expressed in terms of a percentage of combined mine and mill operating cost as a function of remoteness;
- working capital requirement expressed in number of months of operating cost as a function of remoteness;
- number of persons employed as a function of mining method, and mine and mill capacities;
- typical milling recoveries, concentrate grades, and flow of metals among concentrate products, as functions of ore types;

- capital cost of road construction as a function of terrain and distance;
- capital cost of houses, permanent bunkhouse facilities, and townsite amenities as functions of the percentages of employed persons to be accommodated and remoteness;
- capital cost of power facilities as a function of mine capacity, mine location, and remoteness.

With respect to processing facilities, where more than one deposit of the same type exists in a region, deposits are evaluated assuming utilization of a common mill facility. The overall regional mill capacity is specified, as is the distance between the deposit and the mill. The deposit is allocated a proportion of the mill capital cost based on relative capacities. The distance is used to estimate a road-haulage transportation cost for the ore. Additional road construction may be specified. As a variant, an appraisal is also carried out based on the construction of a separate milling facility for each deposit.

The variability of geological, cost, and revenue parameters among mineral deposits is one of the basic characteristics of mineral supply. Cumulative probability distributions have been constructed for selected deposit input parameters to examine this variability. Figures 5 to 7 present cumulative probability distributions of recoverable ore reserves, unit revenue, and unit operating cost for the 291 base metal discoveries in the study data base. Key statistics from the distributions, summarized in table 8, illustrate the high degree of variability existing among individual mineral deposits. For example, there is an almost 200-times difference in ore reserve size between the lower-decile and upper-decile deposits. Also, the size distribution is shown to be highly skewed. There are many small deposits and a few with extremely large recoverable ore reserves. Thus, the mean deposit size is almost three times as large as the upper-quartile deposit and ten times larger than the median or middle value of the distribution. The variability of the unit revenue and unit operating cost distributions are also pronounced. The wide ranges of values for deposit parameters illustrated in figures 5 to 7 give rise to what we have referred to as geologic risk - the variability of returns among economic deposits. This consequence of deposit variability will later be examined.

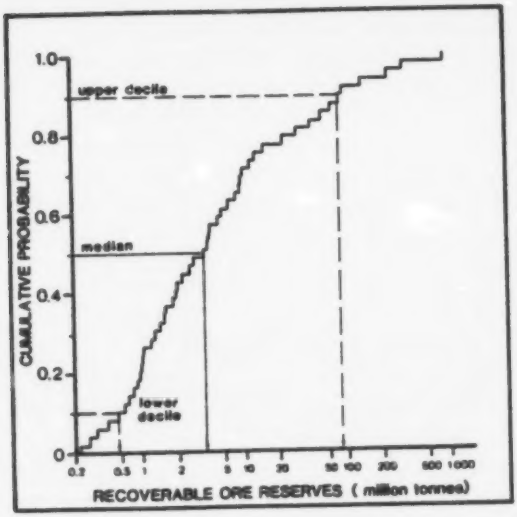

Figure 5. Cumulative Probability Distribution of Recoverable Ore Reserves for 291 Possible Economic Deposits

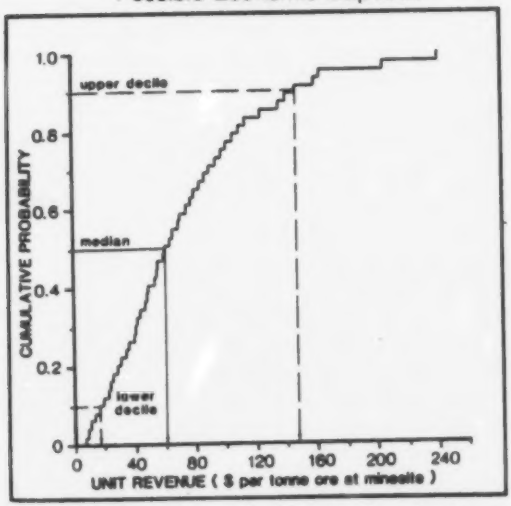

Figure 6. Cumulative Probability Distribution of Unit Revenue for 291 Possible Economic Deposits

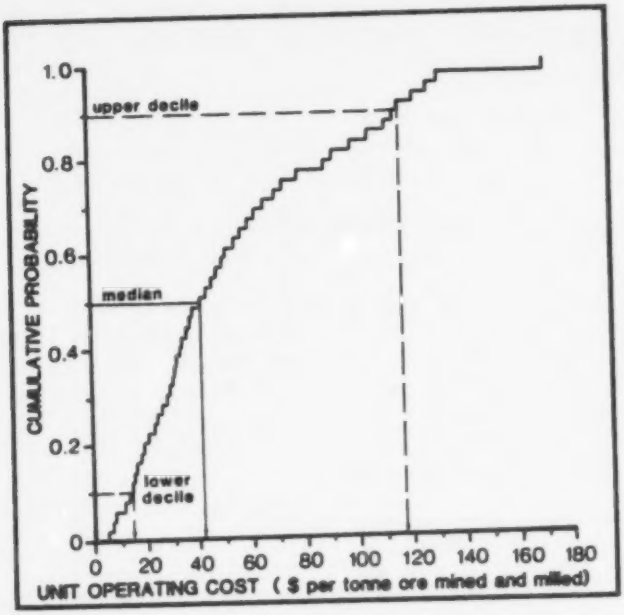

Figure 7. Cumulative Probability Distribution of Unit Operating Cost for 291 Possible Economic Deposits

Table 8

KEY STATISTICS FROM CUMULATIVE DISTRIBUTIONS OF INPUT PARAMETERS FOR 291 POSSIBLE ECONOMIC DEPOSITS

Statistic	Recoverable Ore Reserves (million tonnes)	Unit Revenue ($ per tonne)	Unit Operating Cost ($ per tonne)
Upper decile	78.2	140	113
Upper quartile	11.5	96	71
Mean (average)	30.0	109	51
Median	3.0	59	39
Lower quartile	0.9	34	23
Lower decile	0.4	16	13

Key statistics from more specific cumulative distributions for the 57 significant base metal deposits in the territories and the 234 possible economic discoveries in the provinces are compared in table 9. The mean deposit size is almost twice as large in the provinces, whereas the lower-decile, lower-quartile, and median deposits are larger in northern Canada. This suggests the presence of some extremely large (mainly porphyry) deposits in the provinces. The unit revenue and unit operating cost distributions for the two regions are remarkably similar. The variability of all three parameters is shown to be somewhat greater in southern Canada.

Infrastructure Requirements

The following aspects of infrastructure development are fully costed in our assessment:

- mine access roads to connect with regional networks;
- housing and single-worker accommodation;
- townsite and camp amenities;
- facilities for fly-in work programs;
- power generating and transmission facilities.

The evaluation of deposits is mainly based on existing transportation infrastructure and currently available technology. Base metal concentrates are assumed to be transported to market on all-weather roads, railways, and ships.

The one item of infrastructure not included in the economic appraisal is the capital cost of regional or "development" roads required in situations (particularly in the northeast Mackenzie district) where presently undeveloped deposits are remote from existing transportation routes. The study assumes that government, as in the past, will provide regional roads, not just in the north but throughout Canada, when they can be justified for economic development. While this may not be an immediate prospect, the assumption is justified by the long-term nature of the assessment being carried out - an assessment requiring a perspective of the future going well beyond currently prevailing condi-

Table 9

COMPARISON OF KEY STATISTICS FROM CUMULATIVE DISTRIBUTIONS OF INPUT PARAMETERS FOR POSSIBLE ECONOMIC DEPOSITS IN THE TERRITORIES AND PROVINCES

	Recoverable Ore Reserves (million tonnes)		Unit Revenue ($ per tonne)		Unit Operating Cost ($ per tonne)	
Statistic	The Territories	The Provinces	The Territories	The Provinces	The Territories	The Provinces
Upper decile	50.6	84.1	123	141	112	114
Upper quartile	12.3	12.1	100	94	66	73
Mean (average)	17.2	33.1	117	107	49	52
Median	5.1	2.7	61	59	33	41
Lower quartile	1.2	0.9	40	33	22	23
Lower decile	0.6	0.4	22	14	15	11

tions. The study presupposes that the necessary regional roads will be in place by the turn of the century. Evaluation of the effects of possible cost-sharing and cost-recovery policies for regional roads is an important issue in the north. However, the evaluation of base metal mining undertaken here would have to be extended to cover gold, silver, tungsten, and uranium resources before a comprehensive assessment of these policies would be possible.

Where feasible, it is assumed that existing townsites would be used. In several cases, where the mining of large, presently undeveloped deposits is being considered in semi-remote locations, it is assumed that new townsites would be constructed if and when the deposits warrant development. For example, in the territories, possible new townsites would be constructed at Howards Pass and MacMillan Pass. For deposits in remote locations, evaluation is based on fly-in work programs utilizing the nearest population centres.

The cost of power facilities is based on existing electrical transmission lines. Where feasible, it is assumed that utility power lines would be constructed to connect mining projects with existing grids. Elsewhere, the cost of electricity is based on installation of self-contained diesel generating plants.

Estimation of Remoteness Costs

As outlined earlier in this chapter, capital and operating cost estimates for each of the 291 possible economic discoveries are based, in order of priority, on actual mining company data, feasibility study projections, and order-of-magnitude relationships. The generalized cost functions assume conditions in established mining districts in the provinces such as Bathurst, Val d'Or-Noranda, Timmins, Flin Flon, and south-central British Columbia.

Remoteness costs are introduced into the evaluation in two ways. First, as discussed in the previous section, infrastructure requirements are specified for each deposit based on its location in relation to existing infrastructure.

Second, unit capital cost and unit operating cost premiums are estimated for each deposit, again as a function of its location. The procedure used to estimate these cost premiums is outlined in figure 8. For each deposit, costs are initially subdivided into labour and supply components based on the type of mining operation. Labour rate premiums are then estimated as a function of deposit location relative to established communities in the provinces. These premiums are found to vary from 10 percent to 50 percent.

Next, the amounts of fuel and other supplies required in the construction and operating phases of mining are estimated, per million dollars of capital cost and per million dollars of operating cost.[9] For each deposit, transportation modes are specified and distances estimated by mode from the most convenient supply centres to the minesite. Unit transportation costs for fuel and for other supplies are then combined with these estimates as shown in figure 8 to determine supply cost premiums for the capital and operating cost components.[10]

Finally, the estimated labour and supply cost premiums are combined to derive overall capital and operating cost remoteness premiums for each deposit. These cost premiums are found to range from 5 to 40 percent for deposits in the territories relative to mining costs in the more favourably-located areas of southern Canada.

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9 The breakdown into fuel and other supplies is necessary as transportation costs differ. Furthermore, during the production phase, other supplies can, at least partly, be backhauled using the same transportation facilities that are used to take out the base metal concentrates, thus reducing costs. This is not possible for fuel transportation.

10 In this regard, the following studies have been particularly helpful:

Northeast Mackenzie District Transportation Study: Phase I, L. Dubose, Department of Indian and Northern Affairs, March 1979.

Northeast Mackenzie District Transportation Study: Phase II, Canadian Pacific Consulting Services, August 1980.

An Inquiry into the Transportation Requirements of the Yukon, E. Weinberg, B.M. McLaughlin, N. Thurston; Canadian Transportation Commission, December 1983.

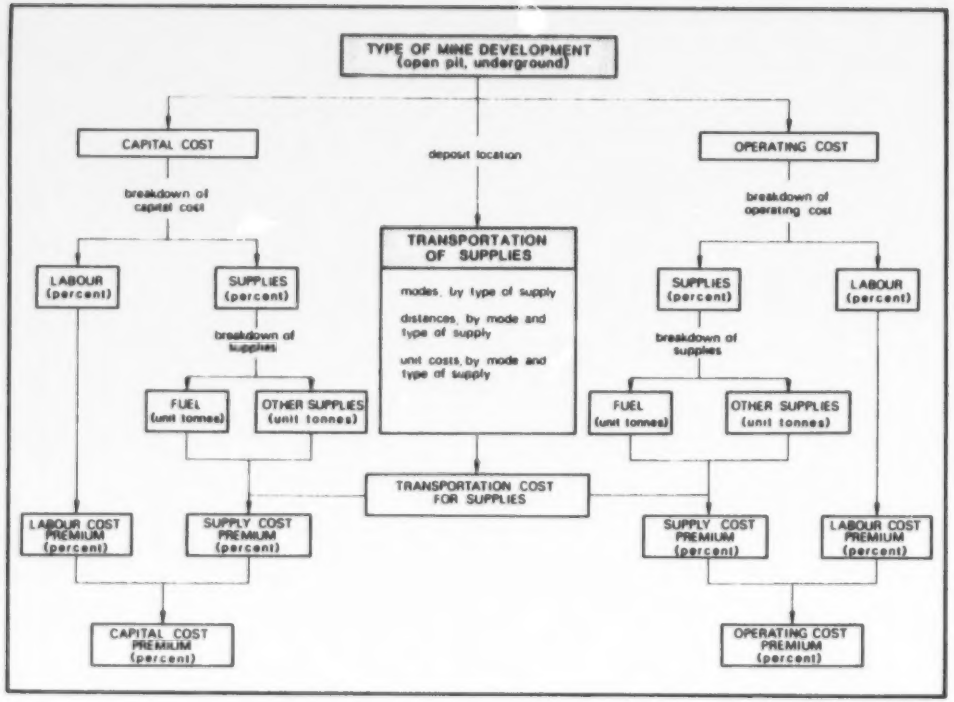

Figure 8. Procedure for Estimating Remoteness Cost Premiums

It should be emphasized that these cost premiums are applied in addition to the following components of remoteness cost which are separately considered in each deposit evaluation:

- the five elements of infrastructure development outlined in the previous section;
- additional working capital requirements;
- the cost of operating a fly-in work program;
- relatively long distances and high transportation charges from minesite to smelter for the concentrate products.

Having adopted this procedure, we are confident that the higher capital and operating costs associated with remote deposit locations have been adequately accounted for in the appraisal.

Critique of the Data Base

The information utilized for this study has been assembled on a continuing basis since 1972. Nevertheless, there are a number of data base limitations.

First, possible economic deposits are classified on the basis of their discovery dates. The discovery date occurs part-way through what in reality is a discovery process. Thus, it is possible that exploration expenditures included in the economic assessment for one time interval may result in discoveries included in the following time interval, or vice versa. Although such discrepancies tend to cancel and should not significantly alter perceived time trends, given the length of the one 16-year and two 8-year intervals considered, they may be important if, as a result, possible economic deposits are excluded from the overall study period. For this reason, two discoveries made at the beginning of 1978 have been included in the evaluation. The 32-year period chosen is considered to be of sufficient duration to minimize these spillover effects.

Second, the data for older mines tends to be more complete than that for the more recent discoveries. This is especially important with respect to ore reserve estimates, since development and production typically proceed on the basis of partial delineation results. Our objective has been to include as complete an estimate as possible for the tonnage and grade characteristics of each deposit. There is nevertheless an

inevitable tendency to undervalue the appraisals, especially for deposits discovered most recently. The undervaluation is particularly significant with respect to ore reserve tonnage. This problem can only be eased by periodic updating and improvement of the data base.

The estimates of total exploration expenditures also have limitations. It is not clear to what extent overhead costs are included in the totals. The instructions provided in Canadian government exploration questionnaires are poorly defined in this regard. Company practices in allocating the overhead component of their exploration expenditures and reporting it on government questionnaires appear to vary widely. Thus, there is scope for improving the completeness and consistency of the exploration expenditure estimates applied in this study.

It can be argued that the use of historical exploration expenditures overstates the exploration costs that would be required under today's conditions. This contention is based on the increasing effectiveness of exploration. Thus, at the present time, lower exploration expenditures would be required to find the deposits which were discovered historically. However, both depletion effects and advances in technology act over time, and may lead to either an increase or a decrease in finding costs, depending on their resultant. In this study, these effects are examined by studying time trends within the overall 32-year study period. Otherwise, it is assumed that the cost of making a future discovery will be similar to the cost in the past.

Finally, there is scope for improving the order-of-magnitude costing functions and the procedure for estimating mining costs for presently undeveloped deposits in remote locations.

These and other shortcomings in the data base reflect a compromise between the ready availability of data and the research limitations imposed by time constraints. While there is room for improvement, it is suggested that the existing data base is sufficient to support a meaningful comparison of the economics of base metal supply in northern and southern Canada.

Data Processing

The data is processed by computer programs developed by Professor Michel L. Bilodeau, Department of Mining and Metallurgical Engineering, McGill University, for the Centre for Resource Studies. There are three

separate procedures which are named MINDEC 1, MINDEC 2, and MINDEC 3.

MINDEC 1 is a program that computes the development and production characteristics of each possible economic discovery. The MINDEC 2 program then retrieves the cash flow elements and economic characteristics of the economic mineral deposits, computes their averages, lists the unit development and production components of cash flow for an economic deposit, and plots cumulative probability distributions. Finally, MINDEC 3 is a program to retrieve the yearly cash flow elements of economic mineral deposits. It then computes the time distribution of average cash flows for an economic deposit and associated economic characteristics with and without the average exploration period cash flows.

Variants for Analysis

To summarize, an assessment of the potential value of base metal mining is initially made for Canada overall using a specified set of "base case" conditions. This provides a standard for comparing the economics of mineral exploration and mine development in the territories and provinces.

The general validity of the comparative base case results is then examined by considering the sensitivity of the potential value indicators to variations in the following study parameters:

- long-term metal price projections;
- cost-of-capital rate;
- minimum size requirement for an economic deposit;
- annual exploration budget;
- separate processing facility for each deposit.

The next step is to analyze time trends in the economics of base metal supply in northern and southern Canada. Economic potential is then more specifically assessed and compared within the shield and cordilleran regions. A detailed evaluation and comparison of the return characteristics of economic base metal deposits next considers:

- cash flow components per tonne of ore;
- return characteristics for specific deposit types;

- comparison of return characteristics for pre-1946 economic discoveries with those of economic deposits found during the 1946-77 period.

Finally, the effects of mining taxation on base metal potential in the territories and provinces are assessed and compared.

4. POTENTIAL VALUE OF BASE METAL MINING

As discussed in chapter 2, the potential value of base metal supply is defined as the difference between the revenues realized from mine production and all the costs required to realize that revenue, including an allowance for the cost of capital.

Canada

The "base case" conditions, which are used as a standard for comparison with more specific results for the territories and provinces, are:

- 229 possible economic deposits discovered in Canada during the period 1946-1977;
- expected metal prices;
- 8-percent cost of capital;
- $20-million minimum acceptable total revenue for an economic deposit;
- utilization of regional mill opportunities;
- $4-million annual exploration budget.

Under these conditions, 100 of the 229 deposits evaluated are found to be economic. The cost and revenue characteristics of the 100 economic deposits are used to assess the time distribution of average cash flows for an economic deposit. These undiscounted results are presented in figure 9 and summarized as follows.

Exploration: approximately 8.5 years with an average exploration expenditure per economic deposit of $34 million;

Development: up to 5 years with an average preproduction capital cost of $103 million per economic deposit;

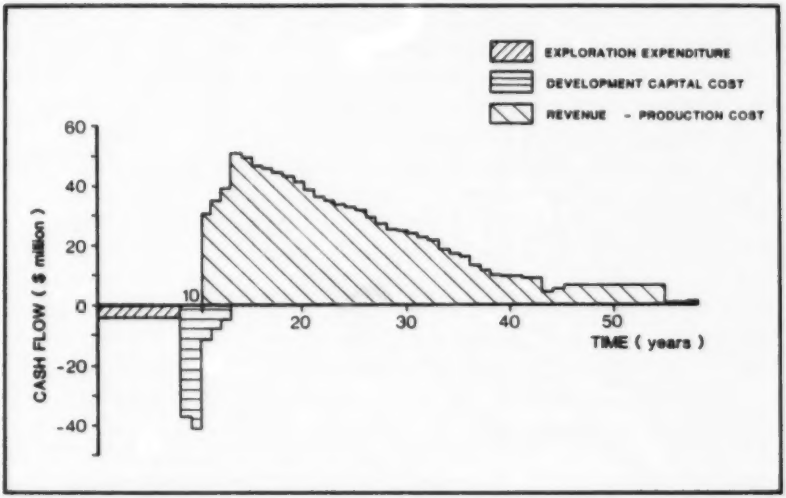

Figure 9. Time Distribution of Average Cash Flows for an Economic Deposit in Canada

Production: up to 48 years with annual cash flows which vary as shown in figure 9.[1] Average values per economic deposit are:
- revenue, $1,666 million;
- production cost, $647 million.

Thus, the average cash flow for an economic deposit is (1,666 - 647 - 103 - 34) = 882 million constant 1983 Canadian dollars.

[1] This does not mean that the average economic deposit produces for 48 years. To correctly account for time value in the assessment, the cash flows of the economic deposits in production each year are divided by (or averaged across) the total number of economic deposits. The average cash flow for an economic deposit generally declines over the production phase because the number of economic deposits remaining in production decreases. Thus, 48 years is the productive life of the longest-lived economic deposit. The average productive life for the 100 economic deposits is in fact about 13 years.

The mean or average return characteristics for an economic deposit can be derived from the development and production phase cash flow estimates. Thus, the average net present value of an economic deposit, discounted back to the start of development using the 8-percent cost of capital, is $266 million. Alternatively, the average return may be expressed as a 36-percent discounted cash flow rate of return.

A high degree of variability is associated with these average return characteristics, illustrating the geologic risk discussed in chapter 2. There is a wide range of total revenues, net present values, and rates of return among the individual economic deposits. To describe this variability, key statistics from the cumulative probability distributions for these return characteristics are presented in table 10.[2] Note that the total revenue distribution for the economic deposits is much more variable and skewed than the rate of return distribution. This difference between size and profitability variations is consistent with the comparative distribution characteristics for recoverable ore reserves and revenue per tonne for all deposits shown earlier in table 8. The net present value statistics reflect a mixture of the deposit size and profitability characteristics.

Table 10

KEY STATISTICS FROM CUMULATIVE DISTRIBUTIONS OF RETURN CHARACTERISTICS FOR 100 ECONOMIC DEPOSITS

Statistic	Total Revenue ($ million)	Rate of Return (percent)	Net Present Value ($ million)
Upper decile	3,620	66	630
Upper quartile	1,766	40	253
Mean(average)	1,666	33	266
Median	586	25	89
Lower quartile	259	15	22
Lower decile	131	10	4

All three return distributions summarized in table 10 are highly skewed, the mean values being significantly higher than the median or middle values of their respective distributions. This indicates that most economic deposits offer relatively modest returns while a few exceptional discoveries yield extremely high returns. The geologic risk portrayed

[2] It may be noted that the mean rate of return for an economic deposit, 33 percent, differs from the weighted rate of return of 36 percent derived from the time distribution of average cash flows for an economic deposit.

here by the total revenue, net present value, and rate of return statistics is a key feature of base metal supply.

The expected value of base metal supply per economic discovery is evaluated as follows. The average net present value at the start of development, $266 million, is discounted back to an average return (R) of $139 million at the start of exploration. The average exploration expenditure of $34 million per economic discovery is equivalent to a discounted value (E) of about $24 million at the start of exploration. Thus, the expected value per economic discovery (EV) is $139 million minus $24 million, or $115 million. This indicates that on average, given the base case conditions, $115 million of new wealth is associated with the discovery of an economic base metal deposit. Alternatively, the expected value of base metal supply may be expressed as a 19-percent rate of return. These results show that base metal supply has the potential to increase substantially the net value or wealth available to Canadian society. They also show that base metal resources in Canada are of high quality.

Aggregate results may be determined by multiplying the average values per economic deposit by the number of economic deposits. Thus, we find:

- total undiscounted revenue, $88.2 billion;
- total net present value at the start of development, $26.6 billion;
- total expected value at the start of exploration, $11.5 billion.

These aggregate measures will subsequently be helpful in interpreting results.

Given this overall Canadian perspective, we now can begin to analyze, compare and explain comparative economic results for northern and southern Canada.

North-South Comparison

In this section, the Canada-wide assessment is subdivided into our two geographical study areas: the territories, and the provinces. All other evaluation conditions remain the same as in the base case.

Exploration-phase results are presented in table 11. Of the 56 significant base metal discoveries in northern Canada, 29 (or 52 percent) are found to be economic. Similarly, 71 (or 41 percent) of the 173 dis-

coveries appraised in the provinces satisfy economic deposit conditions. Base metal exploration in the territories appears to be relatively productive - 10 percent of total Canadian exploration expenditures yield 29 percent of the economic discoveries assessed. The average exploration expenditure per economic discovery in the north, $12 million, is thus found to be much lower than the $43 million average finding cost in southern Canada. The average time required to find and delineate an economic deposit in the territories is as a consequence relatively short, about 3 years at the $4-million exploration budget rate, as compared to almost 11 years in the provinces.

Table 11

EXPLORATION-PHASE RESULTS IN THE TERRITORIES AND PROVINCES

Characteristic	The Territories	The Provinces
Total exploration expenditures ($ million)	337	3,043
Number of economic discoveries	29	71
Average undiscounted exploration expenditure ($ million)	12	43
Average exploration period (years)	3	11
Average deposit size (million tonnes)	26	60

Because of the north's remoteness, one might expect exploration costs per economic discovery to be relatively high. Why then is the average discovery cost so much lower than in southern Canada? Three possible reasons are:

- deposits are easier to find in the territories;
- exploration is more efficient in the territories;
- depletion is more advanced in the provinces.

Deposits may be easier to find in the territories because there is better exposure of bedrock, and because about 64 percent of the area

lies above the treeline (as compared to only 4 percent of the provinces). Exploration may be more efficient in the north to the extent that 10 percent of Canadian expenditures spread over 40 percent of its landmass implies a smaller number of active companies and a lower incidence of re-exploration and overlap. Finally, depletion effects in southern Canada in terms of fewer undiscovered deposits and deeper, more costly exploration programs, may be resulting from a prolonged, intensive exploration history.

As shown in table 11, the average size of an economic deposit in the provinces is found to be more than twice the average deposit size in the territories. As we will see, this difference is mainly caused by the presence of several large economic porphyry deposits in the south.

The time distributions of average cash flows for an economic deposit in the territories and the provinces are illustrated in figure 10 and summarized in table 12. The average revenue generated per economic deposit in the north is somewhat lower than in southern Canada.[3] Since the combined exploration, development and production costs are about

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[3] Considering that the average deposit size in the provinces is about twice the deposit size in the north and total revenues in both areas differ only marginally, one might expect that average ore grades in the north are much higher than in the south. This is not necessarily the case, as demonstrated by the following example (provided by Michel Bilodeau, personal communication, 1983). The recoverable ore reserves and unit revenues (representing grade) of three hypothetical deposits are given. These are multiplied to derive the total revenue for each deposit.

Deposit	Recoverable Reserves (T)	Unit Revenue (R)	Total Revenue (TxR)
A	5	150	750
B	15	90	1350
C	25	30	750
Averages	15	90	950

Tavg. x Ravg. = 15 x 90 = 1350

The discrepancy of 400 (1350 - 950) between the multiple of the average reserves and the average unit revenue, and the average of the three total revenues arises because T and R in this case have a perfect negative correlation (-1.0000). Thus, the correlation between tonnage and grade, which can vary between regions, influences the determination of the average total revenue per economic deposit.

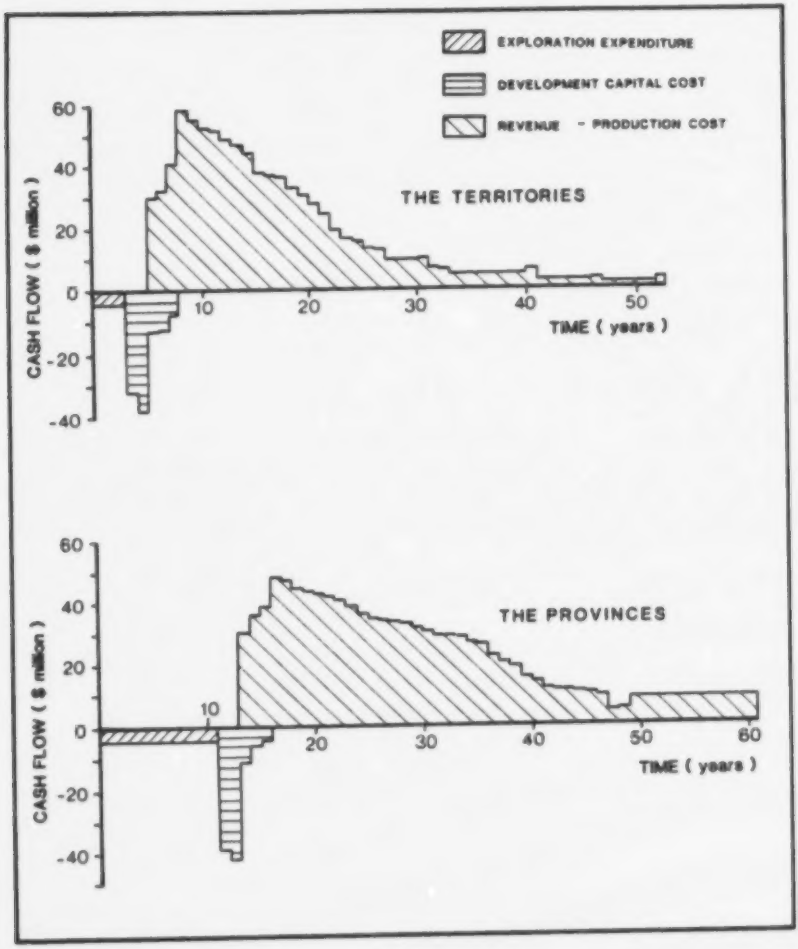

Figure 10. Time Distributions of Average Cash Flows for an Economic Deposit in the Territories and Provinces

the same, the divergence in cash flow results reflects the revenue differential.

Table 12

AVERAGE UNDISCOUNTED VALUES PER ECONOMIC DISCOVERY IN THE TERRITORIES AND PROVINCES ($ million)

Characteristic	The Territories	The Provinces
Revenue	1,563	1,709
- Exploration expenditure	12	43
- Development capital cost	104	103
- Production cost	675	636
Cash flow	772	927

Discounted values at the start of development are compared in table 13. Net present value and rate-of-return indicators are remarkably

Table 13

DISCOUNTED VALUES AT THE START OF DEVELOPMENT IN THE TERRITORIES AND PROVINCES

	The Territories	The Provinces
Net present value per economic deposit ($ million)	263	268
Rate of return (percent)	39	35

similar for the two study areas. This may be considered a surprising result, in view of the relative remoteness of base metal deposits in northern Canada. Possible reasons for the similarity of return characteristics in the territories and provinces, a subject for further examination in this and subsequent chapters, include:

- failure to account for the high development and production costs associated with remote deposit locations;

- greater clustering of deposits in the territories, resulting in infrastructure economies;
- deposits in the north may have higher grades and or more favourable processing characteristics;
- northern deposits may generally occur closer to the surface, enabling the application of lower-cost mining methods;
- a more favourable mix of geological regions and or deposit types in the territories.

A comparison of the variability of revenue, net present value and rate-of-return indicators for economic deposits in the territories and provinces is illustrated in table 14 by key statistics taken from the associated cumulative distributions. The total revenue distributions are shown to be quite similar. However, the southern Canada distribution is more skewed as indicated by the larger difference between the mean and median values. The rate-of-return distribution for economic deposits in the north has more extreme upper and lower limits than for the south. This may result from:

- the influence of marginal porphyry deposits on rates of return in southern Canada;
- higher unit costs associated with a greater proportion of small economic deposits in the provinces;
- depletion effects in the provinces in terms of more deep-seated deposits with higher associated development and mining costs.

It is apparent from the rate of return and net present value statistics presented in table 14 that there is a greater proportion of more marginal economic deposits in southern Canada, illustrated by the comparative lower-quartile and lower-decile values. In northern Canada, a smaller proportion of economic deposits are close to the margin. This difference is significant and will be further discussed when examining the sensitivity analysis results in the next chapter.

Table 14

TERRITORIES-PROVINCES COMPARISON OF KEY STATISTICS FROM CUMULATIVE DISTRIBUTIONS OF RETURN CHARACTERISTICS FOR ECONOMIC DEPOSITS

	Total Revenue ($ million)		Rate of Return (percent)		Net Present Value ($ million)	
Statistic	The Territories	The Provinces	The Territories	The Provinces	The Territories	The Provinces
Upper decile	3,703	3,603	82	51	719	625
Upper quartile	1,943	1,817	58	35	395	195
Mean (average)	1,713	1,709	43	30	280	268
Median	698	455	38	25	131	57
Lower quartile	291	255	22	14	58	18
Lower decile	131	126	18	10	34	6

Discounted cash flow values as viewed from the start of exploration, derived from the time distributions shown in figure 10, are summarized in table 15. Average discovery costs are again shown to be much lower in the territories. While the average net present value per economic deposit at the start of development is similar for the two areas (table 13), the average exploration period in the north is shorter. Consequently, the return at the start of exploration is higher in the territories, $210 million per economic deposit as compared to $117 million in the provinces. The expected value per economic discovery (EV), the difference between the average return (R) and exploration expenditure (E) parameters, is shown to be $200 million in the territories as compared to $89 million for the provinces. Similarly, a significantly higher rate of return is indicated for base metal supply in the north.

Table 15

DISCOUNTED VALUES AT THE START OF EXPLORATION IN THE TERRITORIES AND PROVINCES

Characteristic	The Territories	The Provinces
Average exploration expenditure (E, $ million)	10	28
Average return (R, $ million)	210	117
Expected value (EV, $ million)	200	89
Rate of return (percent)	32	16

Aggregate values for all economic deposits in northern and southern Canada are provided in table 16.[4] Although exploration in the territories represents only about one tenth of the Canadian total, the

[4] The aggregate expected value totals for the territories and provinces do not sum to the Canada-wide assessment cited earlier ($12.1 billion in table 16 as compared to $11.5 billion). This discrepancy arises because the difference in the average exploration period in the north and south (3 versus 11 years) has an exponential effect on the expected value result which involves discounting at $1/(1 + i)^n$. Also, the length of the exploration period is not necessarily directly related to the size of the aggregate expected value. For example, a region characterized by a long exploration period can have either a relatively large or small aggregate expected value.

aggregate expected value created by that activity is shown to be almost as great as that assessed for the provinces ($5.8 billion versus $6.3 billion). These aggregate results provide a reference point for the sensitivity analysis carried out in chapter 5.

Table 16

AGGREGATE VALUES FOR ALL ECONOMIC DEPOSITS IN THE TERRITORIES AND PROVINCES ($ million)

Characteristic	The Territories	The Provinces
Total undiscounted revenue	22,391	65,803
Total net present value (start of development)	7,636	19,007
Total expected value (start of exploration)	5,812	6,333

Effect of Remoteness Costs

The economic comparison made in the previous section indicates that the return characteristics of economic deposits discovered in northern Canada during the 1946-77 period are as attractive as the average values realized for economic discoveries in the provinces. This unexpected result raises doubts as to whether the high development and production costs associated with the less-accessible northern deposits have been fully taken into account.

According to the evaluation procedure adopted, the returns associated with economic deposits reflect the quality of mineral resources discovered. In order to examine the concern about whether our appraisal has adequately allowed for remoteness costs, the locational aspect of a mineral deposit must be separated from other facets of its quality (such as grade, depth, and width). By holding these other facets constant, it is possible to vary deposit location in order to isolate the effects of remoteness cost on the evaluation. This of course can only be done in a hypothetical way.

To illustrate the effects of remoteness costs, six actual deposits which are economic for base case conditions have been selected. Two of these economic deposits occur in the Yukon Territory: one (Y1) is in

a less-remote location and would be mined as an open pit: the other (Y2) is in a relatively remote location and would be developed as an underground mine. Two of the deposits selected occur in the Northwest Territories: one (T1) in a less-remote location would be developed as an open pit: the other (T2) in a remote location would be an underground operation. The remaining two economic deposits occur in well-established mining areas in southern Canada: an underground mine in southern British Columbia (B1), and an underground mine in northwestern Quebec (Q1).

In order to examine the sufficiency of our remoteness cost provisions, the return characteristics for each of these economic discoveries in their actual locations are compared with results evaluated by hypothetically assuming that the deposits situated in the territories and provinces switch places. First, each deposit is evaluated in its own location, as is done in deriving the overall study results. Then, these actual economic deposits are hypothetically relocated as follows:

- Y1, Y2, and T1 are relocated to B1's site in southern British Columbia;
- T2 is moved to Q1's location in northwestern Quebec;
- B1 is relocated in turn to the Y1, Y2, and T1 sites in the Yukon and Northwest Territories;
- Q1 is moved to T2's location in the Northwest Territories.

When the deposits hypothetically change places, new estimates are made for those cost components which are a function of location. Thus, new estimates are in each case derived for concentrate transportation costs, infrastructure development, working capital requirements, the cost of operating a fly-in work program, and capital and operating cost remoteness premiums. All other deposit parameters are assumed to remain the same or, in other words, the non-locational aspects of deposit quality are held constant. The economic return is in each case measured by the net present value at the start of development, using the 8-percent cost-of-capital discount rate. Results are presented in table 17.

Table 17

EFFECT OF REMOTENESS COSTS ON THE NET PRESENT VALUE OF SELECTED ECONOMIC DEPOSITS

Economic Deposit	Assumed Deposit Location	Net Present Value ($ million)
Y1	Y1	58
	B1	86
Y2	Y2	122
	B1	283
T1	T1	170
	B1	235
T2	T2	80
	Q1	175
B1	B1	64
	Y1	-12
	Y2	-36
	T1	9
Q1	Q1	60
	T2	-69

Note: Y, Yukon Territory; T, Northwest Territories; B, British Columbia; Q, Quebec.

The results demonstrate that remoteness costs, as incorporated in our cost estimating procedure, do have a profound influence on the viability of the selected base metal deposits. When the four northern deposits are hypothetically relocated in southern Canada, net present values increase by between $28 million and $161 million, or in other words, by an average of 81 percent over the returns evaluated for the deposits in their actual territorial locations. Similarly, when the two deposits in the provinces are moved to the four northern sites, returns decrease by between $55 million and $129 million or, by an average of 143 percent. In fact, in three of these four cases, the additional remoteness costs render the deposits uneconomic, as indicated by the negative returns in table 17.

These deposit cases illustrate the economic consequences of the higher remoteness costs associated with base metal mining in the north. Our estimating procedure obviously does impose high development and production cost premiums on the less-accessible northern deposits.

Nevertheless, as shown in table 13, the average return characteristics of economic base metal deposits in the territories are just as good as for those occurring in the provinces. Thus, the higher locational costs of the northern base metal deposits must be offset by their superior quality in other respects.

Summing Up

Base metal supply in Canada, assessed in the long term from the start of exploration for a set of base case conditions, is shown to have the potential to increase substantially the wealth available to Canadian society. Findings also demonstrate that base metal resources in Canada are of a high quality.

Comparative results for the territories and the provinces indicate that the economic potential of base metal supply in the north, despite remoteness, is more attractive than in southern Canada. This is found to be attributable to lower exploration costs per discovery in the north coupled with average return characteristics for economic deposits that are comparable to those realized in the provinces. These findings run counter to conventional wisdom which equates "more remote" and "less economic".

The comparative north-south results raise the question of whether adequate allowance has been made in our estimating procedure for the high development and production costs associated with the less-accessible northern deposits. To illustrate the effects of remoteness costs, six base metal deposits which are economic for base case conditions are evaluated first at their actual locations in the territories and provinces and then in alternate locations. Results demonstrate that the method used to estimate mine development and production costs does impose high cost premiums on the deposits located in northern Canada.

5. SENSITIVITY OF NORTH-SOUTH COMPARISON TO KEY STUDY PARAMETERS

The assessment presented in chapter 4 suggests that the potential value of base metal supply in the north is more attractive than in southern Canada. This comparative result is based on a particular set of base case conditions. We are uncertain about a number of the conditions assumed. In the present chapter, the more general validity of this finding is examined by evaluating the sensitivity of the potential value of base metal supply in the territories and the provinces to a wide range of estimates for selected study parameters around the previously assumed base case conditions. The key parameters selected for attention here are metal price, cost of capital, the minimum size requirement, the mineral processing situation, and the annual exploration budget.

Since our focus of attention is the comparison of long-term economic potential in northern and southern Canada, summary results from the sensitivity analysis are expressed as relative percentage changes from the base case values obtained in chapter 4.[1]

Metal Price Variants

The expected metal prices used to this point represent highly uncertain "best" estimates. The sensitivity of potential values in the territories and provinces to the lower-limit and upper-limit metal price projections specified in table 7, are expressed in table 18 as percentage changes relative to the base case assessments. These results indicate the high degree of sensitivity of the economics of the mining sector to metal price conditions. As metal prices rise, there are sharp increases in the number of economic deposits, the average return associated with an economic discovery, and the expected value and rate of return associated with base metal supply. At the same time, higher metal prices reduce the

[1] A percentage change from a base case result is evaluated as follows. First, the result of the sensitivity analysis is subtracted from the value assessed for base case conditions. This difference is then divided by the base case value and multiplied by 100 to determine the percentage change.

average exploration expenditure and time required to discover and delineate an economic deposit.[2]

Table 18

SENSITIVITY ANALYSIS RESULTS FOR METAL PRICE VARIANTS
(percentage change from value for expected prices)

	Lower-Limit Prices		Upper-Limit Prices	
Characteristic	The Territories	The Provinces	The Territories	The Provinces
Number of economic discoveries	-62	-76	+24	+73
Average exploration expenditure (E)	+164	+318	-9	-42
Net present value per economic deposit (start of development)	-78	+12	+94	+53
Rate of return (development and production phases)	-45	+22	+50	+40
Expected value per economic deposit (EV)	-95	-143	+109	+164
Expected rate of return	-69	-73	+53	+79
Total net present value (start of development)	-92	-73	+141	+165
Total expected value (start of exploration)	-98	-110	+159	+357

The number of economic deposits in the provinces is shown to be more sensitive to the range of metal prices examined than in the territories. Consequently, the average exploration expenditure per economic deposit is also more strongly affected.

The economic indicators which measure the development and production phase characteristics of economic discoveries - net present value at the start of development, rate of return for the development and

[2] This is because more discoveries satisfy the "economic deposit" definition and is not due to integral change in the exploration process.

production phases, and aggregate net present value - are generally found to be more sensitive to variations in metal prices in the territories relative to their behaviour in the provinces. As assumed prices are lowered from expected to lower-limit levels, it may be noted that the net present value per economic deposit at the start of development and the rate of return on development and production phase cash flows are actually enhanced. This is because the superior tonnage, grade, and cost characteristics of the select group of deposits that remain economic more than offset the impact of the lower prices on revenue.

Finally, and most importantly, the sensitivity of overall economic indicators - expected value per economic deposit, expected rate of return, and the total expected value - to metal price changes is greater in the provinces than in the territories. In other words, while the potential value of base metal mining deteriorates throughout Canada when future price projections are reduced from expected to lower-limit levels, the competitive standing of the territories relative to the provinces is actually strengthened. This finding calls into question the commonly observed practice of mining companies in tough times such as 1982-86 when exploration budgets are being slashed, to first sacrifice more remote exploration programs and projects.

In summary, the viability of base metal supply in the provinces is found to be more sensitive to possible metal price changes then the situation in the territories.

Cost of Capital Variants

The weighted average cost of capital, assumed to be 8 percent in the base case, is another arguable study parameter. To analyze the sensitivity of potential value indicators to the minimum profitability threshold, the cost of capital is varied from 5 percent to 15 percent. Results are given in table 19. As the minimum rate-of-return requirement is raised, there are significant reductions in the number of economic deposits and in the expected value measures. The cost of capital threshold obviously has a critical bearing on the economics of base metal supply.

Table 19

SENSITIVITY ANALYSIS RESULTS FOR COST OF CAPITAL VARIANTS
(percentage change from value for 8-percent cost of capital)

Characteristic	5-percent Cost of Capital		15-percent Cost of Capital	
	The Territories	The Provinces	The Territories	The Provinces
Number of economic discoveries	+3	+10	-7	-27
Average exploration expenditure (E)	-3	-9	+8	+37
Net present value per economic deposit (start of development)	+40	+40	-51	-42
Rate of return differential[a] (development and production phases)	+8	+2	-19	-3
Expected value per economic deposit (EV)	+55	+127	-63	-103
Expected rate of return differential[a]	+12	+41	-28	-109
Total net present value (start of development)	+45	+54	-54	-57
Total expected value (start of exploration)	+60	+150	-65	-102

a: since the cost of capital is the variable of interest here, these indicators measure the difference between the rate of return and the cost of capital rather than the rate of return itself.

The main findings which emerge from table 19 can be summarized as follows:

- in the provinces, the number of discoveries which satisfy economic deposit conditions and, therefore, the average exploration expenditure per economic discovery, are more sensitive to possible changes in the cost of capital than in the territories;

- the sensitivity of the return characteristics of economic deposits to the cost of capital is generally somewhat greater in the territories;

- the overall economic indicators assessed at the start of exploration for base metal supply in the provinces are shown to be more sensitive to variations in the cost of capital than is the case in the territories.

Risk is sometimes allowed for in mine evaluation practice by adding a premium to the cost-of-capital discount rate. As seen here, the economic consequences of this approach are more severe in southern Canada than in the north. If mining investment in the territories is perceived to be riskier than in the provinces, this practice would appear to be counter productive since higher discount rates are shown to favour exploration and development in the territories relative to the provinces.

The main finding of this section is that the potential value of base metal supply in southern Canada is more sensitive to possible changes in the cost of capital than in the north.

Effect of the Minimum Size Requirement

Most mining companies require that discoveries satisfy a minimum size threshold.[3] This size condition is applied, together with the cost of capital requirement discussed in the previous section, to establish minimum acceptable conditions for an economic deposit. A minimum total revenue of $20 million is assumed in the base case to define economic deposits and to appraise the potential value criteria. Table 20 shows the sensitivity of the expected value assessments to variations in this minimum acceptable size condition. As the minimum total revenue threshold is increased from $20 million to $100 million and then to $250 million, there is a noticeable deterioration in economic results. Economic tradeoffs are obviously involved in screening potentially viable deposits on the basis of size.

[3] The rationale for applying a minimum size cutoff is that the company's senior management, considered to be a fixed resource, should focus their attention on larger deposits which have the potential to make a significant contribution to overall corporate performance. This reasoning, not infrequently encountered, begs the question of why responsibility for small projects should rest with senior management in the first place. Thus, the issue of a minimum size requirement is really one of organizational structure.

Table 20

SENSITIVITY ANALYSIS RESULTS FOR THE MINIMUM SIZE REQUIREMENT (percentage change from value for $20-million size cutoff)

	Minimum Total Revenue			
	$100 million		$250 million	
Characteristic	The Territories	The Provinces	The Territories	The Provinces
Number of economic discoveries	–	-8	-17	-24
Average exploration expenditure	–	+9	+21	+32
Net present value (start of development)	–	+9	+18	+29
Rate of return (development and production phases)	–	+1	–	+2
Expected value per economic deposit (EV)	–	–	+12	-6
Expected rate of return	–	-3	-2	-11
Total net present value (start of development)	–	–	-2	-2
Total expected value (start of exploration)	–	-9	-7	-29

'–': less than 0.5 percent

The main findings arising from table 20 are:

- in the provinces, the deterioration in both the number of economic deposits and the average exploration expenditure per economic discovery as a function of minimum size are more pronounced than in the territories;

- the average return characteristics per economic discovery, particularly the net present value at the start of development, are shown to improve as the minimum size requirement is increased. This makes sense because the smaller deposits are rendered uneconomic by the increasing size threshold;

- the sensitivity of the return characteristics of economic deposits to the size cutoff is greater in the provinces;

- the overall economic indicators generally show that the economic potential of base metal supply in southern Canada is more sensitive to variations in the minimum size condition than in the north;

- the anomalous increase in the expected value per economic discovery in the territories at the $250-million size threshold is a consequence of the resulting improvement in the net present value at the start of development, noted above, which in this instance more than offsets the deterioration in exploration phase conditions.

The sensitivity analysis carried out in this section shows that screening deposits on the basis of an increasingly severe size cutoff, within the $20 million to $250 million total revenue range, has a more harmful impact on the economics of base metal supply in the provinces than in the territories. This is due to the higher proportion of small, potentially economic deposits in the provinces.

Mineral Processing Variant

The base case conditions assume that common processing facilities are utilized wherever possible. The importance of this type of opportunity depends on the extent to which deposits are clustered together. Regional processing opportunities may or may not be fulfilled in practice. Here, this base case condition is compared with an appraisal which assumes that processing facilities are constructed for each deposit. Percentage changes in the potential value indicators from base case conditions are presented in table 21. Results suggest there would be a significant falling off in the economic potential of base metal mining if opportunities for common processing facilities are not realized.

Table 21

SENSITIVITY ANALYSIS RESULTS FOR MINERAL PROCESSING VARIANT
(percentage change from value for common processing facilities)

Characteristic	Individual Processing Facilities	
	The Territories	The Provinces
Number of economic discoveries	-3	-17
Average exploration expenditure (E)	+3	+20
Net present value (start of development)	-9	+16
Rate of return (development and production phases)	-16	-3
Expected value per economic deposit (EV)	-10	-6
Expected rate of return	-13	-8
Total net present value (start of development)	-12	-3
Total expected value (start of exploration)	-13	-22

The comparative north-south findings in table 21 can be summarized as follows:

- the effect of the separate processing requirement on the number of economic deposits and on the average exploration expenditure per economic discovery is more pronounced in the provinces;
- the average net present value of an economic deposit at the start of development increases in the south but decreases in the north as a consequence of the specified change in processing conditions;
- the sensitivity of rate of return at the start of development, expected value per economic discovery, and expected rate of return, to this change is greater for base metal supply in the territories than in the provinces;
- the effect of separate processing facilities on the aggregate expected value for all economic deposits is greater in southern Canada.

The findings presented in table 21 indicate that the effect of the assumed change in processing conditions on the number of economic deposits in the north is negligible. The impact in the territories is therefore in terms of higher cost and lower return characteristics for essentially the same set of economic deposits. In the provinces, on the other hand, the number of economic deposits is significantly reduced. This finding suggests that the viability of a large number of small deposits in the provinces is dependent on the sharing of processing facilities.

In the territories, the relatively large percentage changes in rate of return for the development and production phases, expected value, and expected rate of return, implies a high degree of clustering among economic base metal deposits. The aggregate expected value for all economic deposits in the provinces, however, is more strongly affected by processing conditions. This is likely explained by the relative importance of the reduction in the number of economic deposits in the provinces as compared to the relative importance of the higher cost burden placed on economic deposits in the territories.

Variants with Respect to the Annual Exploration Budget

An annual exploration budget of $4 million, considered to be a most efficient rate of expenditure, is incorporated in the base case. Assessments have also been made for exploration budget rates of $2 million and $6 million per year. Sensitivity analysis results for these variants are summarized in table 22. Since the number of economic deposits does not change, economic indicators for the development and production phases remain constant and are, therefore, not presented.

An increase in the annual exploration budget is shown to have a strong effect on improving the potential value of base metal supply. By reducing the average exploration time required to discover an economic deposit, the time distribution of negative cash flows is compressed and positive cash flows move closer to the present. Although total exploration expenditures and the number of economic deposits remain unchanged, the potential value indicators are thereby enhanced.

Table 22

SENSITIVITY ANALYSIS RESULTS FOR VARIANTS WITH RESPECT TO THE ANNUAL EXPLORATION BUDGET
(percentage change from value for $4-million budget rate)

	$ 2-million Budget Rate		$ 6-million Budget Rate	
Characteristic	The Territories	The Provinces	The Territories	The Provinces
Average exploration expenditure (E)	-10	-28	+4	+13
Average return (R)	-20	-56	+8	+31
Expected value per economic deposit (EV)	-21	-56	+8	+38
Expected rate of return	-8	-27	+2	+13
Total expected value (start of exploration)	-21	-65	+8	+38

The apparent improvement in potential value associated with increasing the annual budget rate will not in fact be realized if the actual exploration budget exceeds the bounds of organizational efficiency. Thus, increasing the annual exploration budget beyond the most efficient rate can be counterproductive.[4]

The findings presented in table 22 consistently show that the viability of base metal supply is more sensitive to changes in the exploration budget rate in the provinces than it is in the territories. In chapter 4, we found that the average exploration period in the provinces is much longer than in the north, about 11 years as compared to 3 years for base case conditions. The discounting procedure used to assess the potential value indicators is an exponential function of the time period involved. Since a specified change in the exploration budget rate results in the same proportional change to the average exploration periods in the north and south, the effects, as shown, are strongest in southern Canada.

[4] See footnote 4, chapter 3.

Explaining the Comparative North-South Sensitivities

The sensitivity analysis carried out in this chapter demonstrates that the economic viability of base metal supply in the provinces is more sensitive to possible variations in the key study parameters examined than is the case in the territories. An explanation for this finding is now in order.

The greater sensitivity of the economic indicators in the provinces to changes in the exploration budget rate has a specific explanation: the average exploration period is longer in the south and, therefore, the impact of time value on a fixed proportional change in the length of the exploration period is greater.

With respect to the other parameters analyzed in this chapter - metal price, cost of capital, the minimum size cutoff, and the processing situation - the higher degree of sensitivity of results in the provinces can be explained mainly by the different distribution characteristics of potential economic deposits in the north and south. Specifically, it is the distribution characteristics in the vicinity of the economic margin which are of interest. The viability of the marginal deposits is most sensitive to the variables examined.

Base metal resources in the provinces include a greater proportion of smaller, more marginal, potential economic deposits. This has already been illustrated by the key statistics presented in table 14. In southern Canada, the lower-quartile and lower-decile net present values and rates of return for economic deposits are significantly lower than in the territories. This explains why the variations in study parameters evaluated have a greater impact on the number of economic deposits in the provinces and, thereby, a relatively strong influence on the potential value measures.

To further illustrate this important difference, figure 11 presents cumulative probability distributions of net present value for economic deposits in the two study areas. These distributions, evaluated for base case conditions, are the source of the net present value statistics presented in table 14. The higher proportion of smaller, more marginal economic deposits in the provinces can now perhaps be more clearly seen. For example, consider a net present value limit of $10 million. Figure 11 shows that while 13 percent of the economic deposits in the provinces have net present values equal to or lower than this value, only about 3 percent of the economic deposits in the territories fall within this interval. Similar differences exist through the entire range of net present values. Therefore, the effects of specified changes in metal price, cost of capital, the minimum size cutoff, and the mineral processing situation,

inevitably have a stronger impact on the economics of base metal mining in the provinces.

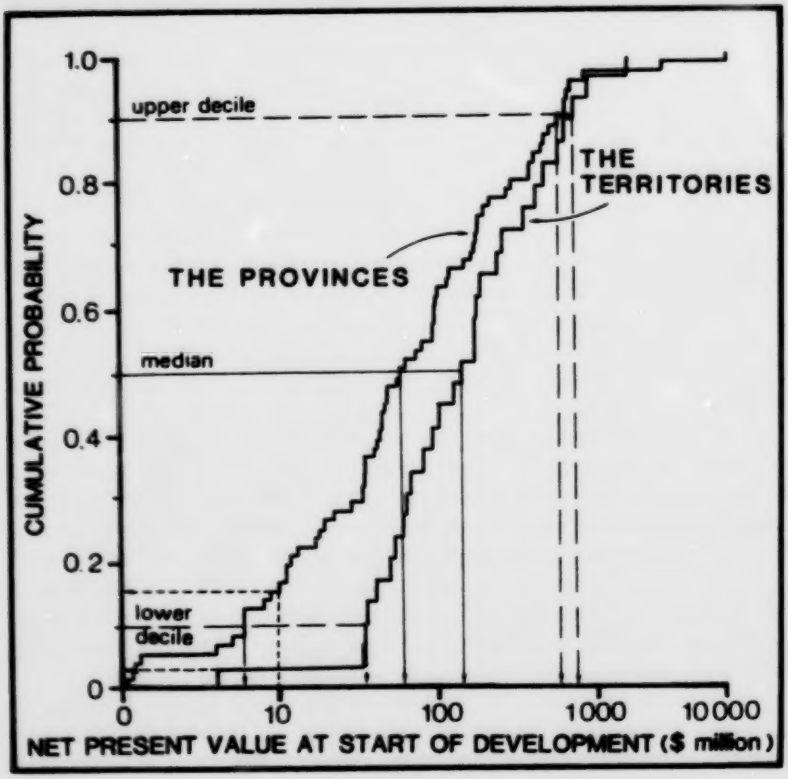

Figure 11. Cumulative Probability Distributions of Net Present Value in the Territories and Provinces

Summing Up

We have tested the base case findings presented in chapter 4 for a wide range of possible future conditions. The sensitivity analysis carried out confirms that the economic potential of base metal supply in the territories is significantly greater than in the provinces.

The viability of base metal supply in the provinces is generally found to be more sensitive to possible changes in key study parameters. This is explained mainly by the greater proportion of more marginal economic deposits in southern Canada.

If the specified base case conditions are viewed as being too optimistic, it should be noted that the assumption of less-favourable conditions with respect to metal prices, cost of capital, the minimum size requirement, the mineral processing situation, and the exploration expenditure budget rate, all tend to enhance the competitive standing of base metal supply in the territories relative to the provinces. In other words, while less-favourable conditions for these parameters cause a general deterioration in economic results, their negative impact is more pronounced in the provinces than in the territories.

6. DYNAMICS OF THE SUPPLY PROCESS: TIME TRENDS IN NORTHERN AND SOUTHERN CANADA

The assessments presented and analyzed to this point aggregate base metal mining activity for the 1946-77 period. In using historical experience to support future planning, it is important to try to detect time trends in the supply process. What changes have occurred over the 32-year study period? According to the methodology adopted in chapter 2, time trends assessed in the economics of base metal supply are the resultant of two forces: depletion effects on the one hand, and the effects of improved geological concepts and advances in exploration technology on the other.[1] This dynamic aspect of base metal mining is now examined.

Three time intervals have been selected as being pertinent: a 16-year interval, 1946-61, followed by two 8-year intervals, 1962-69 and 1970-77. While this subdivision is to some extent arbitrary, as explained in chapter 3, it is intended to balance the need for a sufficient number of points to detect time changes, and the requirement for a meaningful sampling of exploration and discovery experience within each interval.

Time Trends in Potential Value

Time trend appraisals for a selected group of potential value indicators are presented in table 23 and figure 12. Monetary values are once again expressed in constant 1983 Canadian dollars. With respect to exploration expenditures, there has been a substantial increase in activity in the territories over the study period, starting from a very small base in 1946-61. The rate of exploration in the provinces increased in 1962-69, over the rate in 1946-61, but subsequently declined modestly. Conse-

[1] These time trends do not take into account the real changes in mineral market conditions or the improvements in mining and mineral processing technologies which have taken place during the respective study periods. In our evaluation, these factors are standardized on the basis of current outlook conditions. The intention is to isolate those aspects of the supply process which have resulted from the changing nature of exploration and from changes in mineral endowment characteristics as revealed through the base metal deposits discovered.

quently, while exploration expenditures in the north account for only 4 percent of Canada-wide expenditures in 1946-61, the territories' share is almost 17 percent for the most recent 1970-77 interval.

Table 23

TIME TRENDS IN POTENTIAL VALUE ASSESSMENTS

	The Territories			The Provinces		
Characteristic	1946 -61	1962 -69	1970 -77	1946 -61	1962 -69	1970 -77
Total exploration expenditures ($ million)	40	110	187	1,004	1,097	942
Number of economic discoveries	6	9	14	37	20	14
Average undiscounted exploration expenditure ($ million)	7	12	13	27	55	67
Average deposit size (million tonnes)	7	20	38	18	168	14
Net present value per economic deposit (start of development, $ million)	108	269	326	180	546	101
Rate of return (development and production phases, percent)	36	46	36	30	41	25
Expected value per economic deposit (EV, $ million)	89	202	241	87	157	-9
Expected rate of return (percent)	30	35	30	18	18	7

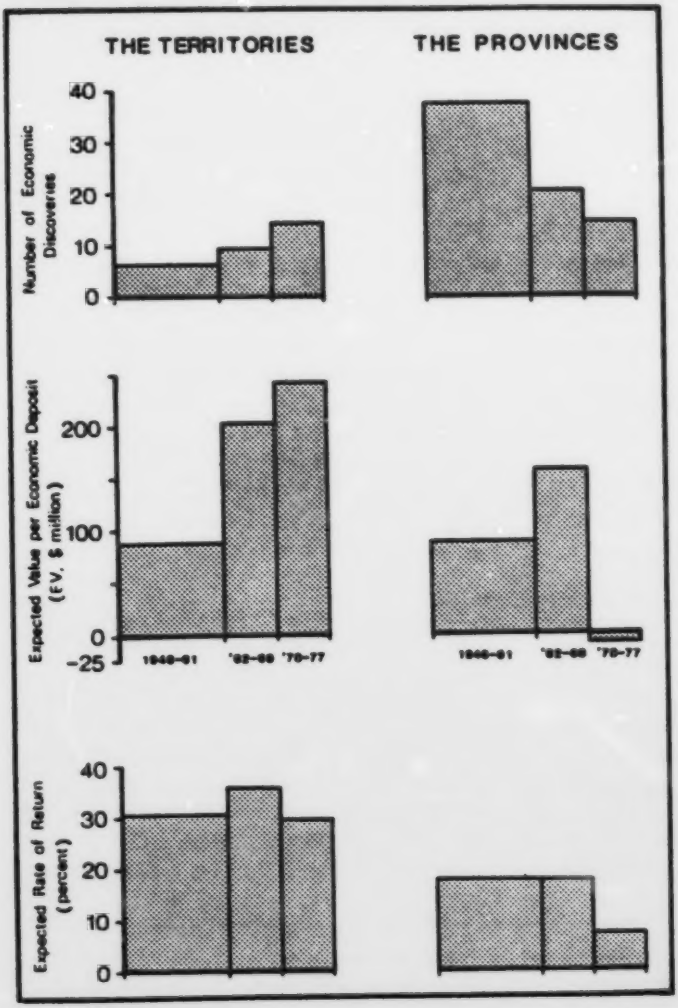

Figure 12. Time Trends in Key Economic Indicators in the Territories and Provinces

The rate of economic discovery in the north is also shown to have increased significantly during the study period, while the discovery rate in the provinces has been more or less constant. The number of economic deposits discovered in the territories and provinces in the 1970-77 interval is identical.

Total exploration expenditures and the number of economic deposits are combined to determine the average cost of finding an economic deposit. While average discovery costs are much lower in the north than in the south throughout the study period, time trends in the two areas are similar. Average exploration expenditures per economic discovery in both cases approximately double between the first and second intervals, then rise more modestly to 1970-77. The overall rate of increase is somewhat lower in the territories.

With respect to the average size of an economic discovery, the most notable feature in table 23 is the influence of several large porphyry deposits discovered during the 1962-69 interval on the provincial economic assessments. The increase in average deposit size in the territories with time is also significant.

Regarding the return characteristics of economic deposits, the average net present value at the start of development reflects the changes in average deposit size. Profitability, as measured by rate of return, appears to remain at a high level throughout the study period. In both areas, the rate of return is greater in 1962-69 than in 1946-61 and then declines for the 1970-77 interval.

Finally, the return characteristics of economic discoveries are combined with the exploration expenditure estimates to determine the potential value of base metal supply as shown in table 23. In the territories, the expected value per economic discovery more than doubles over the first two intervals before increasing more modestly in 1970-77. The expected rate of return also increases in 1962-69 over the 1946-61 interval before declining to about its original level. The improvement in expected value between the first and second intervals appears to be the result of both larger and more profitable economic discoveries. The more modest gain shown from 1962-69 to 1970-77 is attributable to the larger size of the economic deposits discovered more than offsetting their lower rate of return. The increases previously noted in the average exploration expenditure per economic deposit appear to be largely offset by the better return characteristics of the economic discoveries. The variations shown in the expected rates of return are of no particular significance.

In the provinces, a substantial increase in the expected value per economic discovery may be noted over the first two intervals, but then results turn negative for 1970-77. The expected rate of return remains constant in 1946-61 and 1962-69 before deteriorating to 6.8 percent for the most recent 1970-77 interval (as compared to the 8-percent cost of capital). The uneconomic results for 1970-77 are shown in table 23 to be attributable to high discovery costs coupled with the relatively small size and low profitability of the economic deposits found.

Several possible reasons are advanced to explain the deterioration noted in the provinces:

- the somewhat arbitrary selection of time intervals;
- the tendency to undervalue more recent economic discoveries, as noted in the data base critique in chapter 3;
- long-term depletion effects in terms of both increasing discovery costs and lower-quality economic discoveries;
- no significant improvement in geological concepts and exploration technology.

The results presented in table 23 and analyzed here indicate both increasing activity and improving potential values in the territories from a small 1946-61 base. The provinces on the other hand are characterized by much more intense levels of activity throughout the study period, and a decline in overall economic performance. The amount of exploration in the north, even at the end of the study period, is only about one fifth the level of activity in the south.

To provide more insight into the time trends in potential value discussed here, the changing mixture of base metal exploration methods employed in the two areas is now considered.

The Changing Mix of Discovery Methods

To further examine the dynamics of the exploration and discovery process in the territories and the provinces, a tabulation has been made of discovery methods for all 291 possible economic deposits in our data base. The classification of discoveries in this way is complicated by two factors. First, it may be argued that before any exploration methods are used, some type of geological thought process leads to the selection of areas for exploration and, therefore, in this sense all deposits found are

"geological" discoveries. Second, more than one exploration method is inevitably involved in the discovery of each deposit.

The intent of the procedure adopted here is to classify each discovery according to the main method which was used at the reconnaissance stage. The main purpose of the classification is to compare the changing balance of exploration in the territories and provinces between the relatively low-cost prospecting method and more-expensive indirect geoscience approaches. Four primary modes of discovery are considered: prospecting, geological, geophysical, and geochemical methods.[2]

A discovery is considered to be attributable to the "prospecting" method if the deposit was found on the basis of surface indicators. Thus, prospecting includes the traditional examination of outcrops as well as more modern approaches, such as the use of visual airborne surveys to locate gossans. The "geological" technique is judged to be the discovery method if the deposit is indicated by geological interpretation before other methods are applied. An example of this method is geological definition of a grid drilling program.

The "geophysical" method, including airborne and ground magnetic, electromagnetic, and induced polarization techniques, detects deposits based on the physical properties of the earth's crust. In this way, subsurface deposits can be located by their magnetic or conductive properties. The "geochemical" technique focuses on the primary or secondary dispersion of trace elements around base metal deposits. By systematically sampling large areas, such dispersion "haloes" can be detected, sometimes leading to the discovery of a deposit.

A detailed time series classification of base metal discovery methods can be found in appendix IV.[3] These results are summarized in table 24. The percentage of discoveries attributable to each method is shown for all 291 deposits discovered to 1977, as well as by time interval, with deposits found prior to 1946 considered as a separate category.

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[2] Derry (1970) and Derry and Booth (1978) carried out more extensive studies of the exploration history of Canadian deposits and their discovery methods. Their results differ only modestly from the findings presented here, mainly because their work, not restricted to base metals, included other metallic deposits. According to their definition, the designated discovery technique is the method that played the most important role in the discovery of each deposit.

[3] The findings presented in appendix IV, which use shorter time intervals, are consistent with those presented here.

Table 24

TIME TRENDS IN DISCOVERY METHODS
(percentage of deposits discovered by method)

Discovery Method and Region	Discovery Date					Total
	Pre-1946	1946-61	1962-69	1970-77	1946-77	
Prospecting						
The territories	100	100	60	49	63	66
The provinces	93	44	45	24	39	53
Geological						
The territories	–	–	5	7	7	6
The provinces	2	7	8	12	9	7
Geophysical						
The territories	–	–	35	22	20	19
The provinces	5	46	34	55	45	35
Geochemical						
The territories	–	–	–	22	10	9
The provinces	–	3	13	9	7	5

With regard to the Canada-wide findings, prospecting is shown to be the most important method, accounting for over half of the base metal discoveries. The geophysical method is also important, while the geological and geochemical approaches are found to be less significant as primary discovery tools.

Prospecting has been responsible for a relatively high proportion of the base metal discoveries in the territories - 63 percent as compared to 53 percent in the provinces. Even during the most recent 1970-77 interval, almost half of the deposits discovered in the north are attributable to prospecting. Since 1962-69, the geophysical approach has also been significant in the territories as has geochemistry in the 1970-77 interval. The geological method has played a modest role since 1962-69.

Prospecting was predominant in southern Canada prior to 1946 while the geophysical method is found to be most important throughout the 1946-77 period; 45 percent of the total discoveries in the study period are attributable to the geophysical method. A high but declining proportion of the base metal deposits in the provinces have been discovered by prospecting. On the other hand, the geological and geochemical approaches have become increasingly significant.

For study purposes, the most germane factor is the share of discoveries attributable to the low-cost prospecting approach. The role of this method is a function of four factors.

1. The success of prospecting as an exploration tool depends on the degree to which surface bedrock can be observed and tested.

2. Prospecting will tend to be the dominant method in the initial stages of exploration within an area, and then should systematically decline as surface indicator discovery possibilities become exhausted.

3. The importance of prospecting should be an inverse function of the level of exploration technology available.

4. Application of the prospecting approach depends on the relative costs of alternative discovery methods.

Let us now examine the relative significance of each of these factors with respect to the observed time trends in the territories and provinces. The opportunity to observe the surface exposure of bedrock is better in the north for two reasons. First, the degree of bedrock exposure is somewhat greater in the north. We estimate that about 24 percent of the north consists of areas in which bedrock makes up most of the surface as compared to 20 percent in the provinces. More importantly, approximately 64 percent of the territories lies above the treeline as compared to only 4 percent in the south. Thus, outcrops in the north tend to be more readily observable.

Base metal exploration and discovery in southern Canada is at a more mature stage than in the north. This is illustrated by the large number of deposits discovered prior to 1946 in the provinces, and by the intensive level of exploration activity that took place there during the 1946-77 period. Thus, remaining surface discovery possibilities in the provinces are no doubt more limited than in the territories.

Significant advances in mineral exploration technology have been achieved during the study period. It is reasonable to assume that the range of geoscience technologies available for exploration in northern and southern Canada is, at any point in time, similar.

The cost premiums associated with exploration in remote areas should have a greater impact on exploration programs utilizing the indirect methods which require more technical and logistical support than on the more direct prospecting approach. Thus, there would appear to be

a relative cost advantage in using the prospecting method in the territories as compared to its application in the provinces.

These four factors determine the role of the prospecting method in the territories and provinces. The decreasing share of discoveries attributable to this approach with time in both the north and the south is due to the gradual exhaustion of surface indicator discovery possibilities, and to the significant advances that have been made in exploration technology. The relative importance of the prospecting method in the territories is no doubt due to the lower level of exploration carried out to date, more favourable outcrop conditions, and the relative cost advantage of the prospecting approach in less-accessible areas, perhaps in that order of importance.

The changing mix of discovery methods analyzed here helps explain the comparative north-south exploration expenditures per economic discovery presented in chapter 4, as well as the time trends shown in table 23. The key factor appears to be the quite different levels of exploration maturity in the territories and the provinces to 1977. In this regard, it is interesting to note in table 24 that the proportion of discoveries attributable to prospecting is higher in the north during the most recent 1970-77 interval than at any time since 1946 in southern Canada. Furthermore, while breakthroughs in the application of geophysical methods to base metal exploration were introduced in the early 1950s, and since then have continued to be the dominant discovery method in the provinces, geophysics only appears as a primary discovery tool in the territories starting in 1962-69. These observations suggest that base metal exploration and discovery in the territories lags behind the provinces by 20 years or more. In light of the comparative results presented in this chapter for the most recent 1970-77 interval, it would be remarkable if this time lag does not continue well into the future.

Summing Up

The analysis of time trends in exploration expenditures, return characteristics, potential values, and discovery methods demonstrates that base metal supply in the territories and the provinces are at quite different stages of maturity. The base metal experience in the territories documented for the 1946-77 period appears similar to base metal exploration and development in the provinces prior to World War II. It is suggested that this time lag is the main reason for the relatively low average costs

associated with the discovery of economic deposits in the north. More broadly, the comparative time trends in the base metal supply process explain:

- the increasing activity and improving potential values with time in the territories;
- the apparent decline in overall economic performance in the provinces.

7. COMPARATIVE NORTH-SOUTH ASSESSMENTS BY GEOLOGICAL REGION

Overall differences in the potential value of base metal supply in the territories and provinces, examined in chapters 4-6, are no doubt influenced by the distinct mixtures of geological environments which occur in the two study areas. In this chapter, comparative north-south assessments are made within two major geological provinces: the shield and cordilleran regions. In so doing, inferences are also drawn concerning the effect of other constituent regions. Results are once again summarized using selected potential value indicators. A synopsis of the four main geological regions hosting base metal deposits in Canada is given in appendix V.

Shield Region

The shield region has traditionally been the focus of base metal mining in Canada. During the period of study, 29 percent of the total exploration expenditures in the territories and 50 percent of the expenditures in the provinces were invested in this region (table 3).

Economic indicators for the shield region are given in table 25. The level of activity in the north is shown to be quite low, representing only 6 percent of total exploration expenditures in this geological region and yielding only 5 economic discoveries. This limited experience suggests that the average exploration expenditure per economic discovery in the territories is only about one half of that required in the southern shield.

With regard to the return characteristics of economic deposits discovered, the average deposit size in the south is more than double that assessed for an economic deposit in the north. This size differential is reflected in the higher average net present value at the start of development evaluated for an economic discovery in the provinces. The deposits in the provinces are also more profitable on average, as shown by the higher rate of return for the development and production phases.

Table 25

POTENTIAL VALUE ASSESSMENTS FOR THE SHIELD REGION

Characteristic	The Territories	The Provinces
Total exploration expenditures ($ million)	99	1,540
Number of economic discoveries	5	38
Average undiscounted exploration expenditure ($ million)	20	41
Average deposit size (million tonnes)	6	14
Net present value per economic deposit (start of development, $ million)	218	265
Rate of return (development and production phases, percent)	40	58
Expected value per economic deposit (EV, $ million)	133	95
Expected rate of return (percent)	26	18

In terms of the overall potential value indicators, the more favourable exploration characteristics in the territories outweigh the more attractive return characteristics in the provinces. Consequently, the expected value per economic discovery and the expected rate of return are both shown to be significantly higher in the northern shield.

Cordilleran Region

Base metal mining in the cordilleran region has become increasingly important. During the 1946-77 study period, 60 percent of base metal exploration expenditures in the territories and 34 percent of total expenditures in the provinces were invested in this region (table 3).

Table 26 presents economic indicators for the cordilleran region. Exploration activity in the territories is shown to have accounted for 26 percent of total exploration expenditures in this geological region during the study period and, significantly, 42 percent of the total number of economic deposits appraised were discovered in the north. Consequently, the average exploration cost per economic discovery in the territories is only about one quarter of that assessed in the provinces.

Table 26

POTENTIAL VALUE ASSESSMENTS FOR THE CORDILLERAN REGION

Characteristic	The Territories	The Provinces
Total exploration expenditures ($ million)	202	1,027
Number of economic discoveries	14	19
Average undiscounted exploration expenditure ($ million)	14	54
Average deposit size (million tonnes)	43	178
Net present value per economic deposit (start of development, $ million)	301	229
Rate of return (development and production phases, percent)	32	22
Expected value per economic deposit (EV, $ million)	215	48
Expected rate of return (percent)	26	12

The average size of an economic deposit in the provinces is shown to be approximately four times greater than in the north. However, the profitability of the southern discoveries is significantly lower, as indicated by the 22-percent average rate of return for the development and production phases relative to the 32-percent rate of return achieved in the

territories. The relatively large size and low profitability of economic deposits in the southern cordilleran, as will be shown in the next chapter, mainly reflect the influence of the porphyry discoveries. The combined effect of these size and profitability differences is that the average net present value at the start of development for an economic discovery in the northern cordilleran region is higher than in the south.

Base metal supply in the northern cordilleran region is characterized by much lower exploration costs and somewhat more favourable return characteristics for the economic deposits discovered. Thus, the overall potential value indicators within the cordilleran region - the expected value per economic discovery and the expected rate of return - are substantially higher for the territories than the provinces.

Other Regions

In northern Canada, the platform region, which is the setting for the base metal mining complex at Pine Point and the Polaris deposit, is the "other" geological region of economic interest. During the study period, exploration expenditures in the platform region comprised 11 percent of the total for the territories (table 3).

In terms of base metal potential in the provinces, the "other" geological area of interest is the appalachian region of eastern Canada. The appalachian region accounted for 16 percent of base metal exploration expenditures in the provinces during the period 1946-77 (table 3).

The relative economic attractiveness of these other regions can be illustrated by the potential value indicators shown in table 27 for the territories, and in table 28 for the provinces. In the north, the platform region is shown to yield expected values that are superior to both the shield and cordilleran regions. The appalachian region in southern Canada also has relatively high expected values. Results for the platform region in the territories are, however, found to be more attractive than those of the appalachian region in the provinces.

Table 27

EXPECTED VALUES IN THE TERRITORIES BY GEOLOGICAL REGION

Characteristic	Geological Region		
	Shield	Cordilleran	Platform
Expected value per economic deposit (EV, $ million)	133	215	215
Expected rate of return (percent)	26	26	55

Table 28

EXPECTED VALUES IN THE PROVINCES BY GEOLOGICAL REGION

Characteristic	Geological Region		
	Shield	Cordilleran	Appalachian
Expected value per economic deposit (EV, $ million)	95	48	149
Expected rate of return (percent)	18	12	20

Relative Favourability of the Mix of Geological Regions

Canada-wide appraisals of expected value by geological region are presented in table 29. In order of economic potential, the regions rank as follows.

1. Platform region
2. Appalachian region
3. Shield region
4. Cordilleran region

The relative mixture of geological regions in the territories and provinces by surface area is shown in table 30. Base metal potential in the part of the platform region which occurs in the provinces is buried

under a thick layer of sediments. Consequently, little base metal exploration has been carried out to date and no significant deposits have been discovered.

Table 29

EXPECTED VALUES IN CANADA BY GEOLOGICAL REGION

Characteristic	Geological Region			
	Shield	Cordilleran	Platform	Appalachian
Expected value per economic deposit (EV, $ million)	99	101	215	149
Expected rate of return (percent)	19	16	55	20

Table 30

DISTRIBUTION OF GEOLOGICAL REGIONS (percent of surface area)

Region	Geological Region			
	Shield	Cordilleran	Platform	Appalachian
The territories	43	16	41	–
The provinces	50	15	30	5

It can be inferred from the results presented that northern Canada comprises a mixture of geological regions that is at least as promising for base metal supply as the blend of environments occurring in the provinces.

Summing Up

The results presented in this chapter are consistent with our main study finding. Within each of Canada's two most important geological provinces - the shield and cordilleran regions - the potential value of base metal mining in the territories is more favourable than in the provinces. The difference is particularly pronounced in the cordilleran region. The north's relative attractiveness within the shield region is more marginal,

and also more uncertain, in view of the low level of exploration and discovery experience in the territories to date. The validity of the overall north-south results is confirmed in these more specific cases. Furthermore, there are indications that the mix of geological regions in the territories may be more favourable for base metal supply than the blend of environments found in the provinces.

8. THE RETURN CHARACTERISTICS OF ECONOMIC DEPOSITS IN NORTHERN AND SOUTHERN CANADA

Despite high remoteness costs, the return characteristics associated with economic discoveries in northern Canada are shown in chapter 4 to be comparable to the returns offered in the provinces. The purpose of this chapter is to carry out more detailed examinations of the reasons for this similarity.

In an endeavour to explain the comparative north-south return characteristics, our analysis is extended in three directions.

1. The return characteristics of economic discoveries are disaggregated by considering the cash flow components per tonne of ore. These components help explain similarities and differences in the nature of base metal potential in northern and southern Canada.

2. Following on from our appraisal by geological region in chapter 7, the analysis of discovery characteristics is carried one step further in terms of geological consistency by comparing the average return characteristics of economic deposits in northern and southern Canada classified by deposit type. Three main deposit types are considered: volcanic-associated massive sulphide deposits, sediment-hosted massive sulphide deposits, and porphyry deposits.

3. The time frame of historical experience is extended to include base metal deposits discovered prior to 1946. This is done to provide a more complete picture of the revealed endowment characteristics of base metal deposits. Building on the results presented in chapter 6, this assessment also permits a more extensive consideration of time trends. For this purpose, the average return characteristics for pre-1946 economic discoveries are compared with those for the 1946-77 period.

Each section incorporates three types of results. First, an evaluation is made of the return characteristics of economic deposits. Then, the cash flow components per tonne of ore are analyzed. Finally, an appraisal is made of the average metal product mix recoverable from

these ores.[1] The procedures used for these assessments have been outlined in chapter 2.

Cash Flow Components for Economic Deposits

As shown in chapter 4 (table 13), the average return characteristics of economic deposits in the territories and the provinces are remarkably similar in terms of both net present value and rate of return. The unit cash flow components for an economic discovery in the two study areas are presented in table 31. The main findings are:

Table 31

AVERAGE DEVELOPMENT AND PRODUCTION PHASE COMPONENTS OF CASH FLOW FROM ECONOMIC DEPOSITS IN THE TERRITORIES AND PROVINCES ($ per tonne of ore)

Component		The Territories	The Provinces
Gross in-situ value		203	193
Less:	Mining losses	21	27
	Milling losses	21	30
	Smelting and refining charges	57	42
	Concentrate transportation costs	17	7
Revenue at the minesite		87	87
Less:	Preproduction capital expenditures	11	12
	Production costs	34	36
Before-tax cash flow		42	39

- the average grade of ore, as reflected by the gross in-situ value per tonne, is shown to be marginally higher in the north;
- economic deposits in the territories incur lower mining losses. This indicates that the northern discoveries tend to be relatively close to

[1] The product mix evaluated depends on relative metal prices. The metal shares assessed here are based on expected price conditions (table 7).

the surface, enabling more widespread use of open pit methods, with correspondingly higher ore recoveries;

- lower milling losses are associated with the northern deposits. This suggests that the mineralogy of the ores tends to be relatively simple, enabling the realization of higher metallurgical recoveries;

- more onerous concentrate treatment charges for the economic deposits in the territories essentially offset the lower mining and milling losses incurred. The higher smelting and refining costs result from the high proportion of zinc in the northern ores. Zinc concentrates bear relatively heavy treatment charges;

- much higher concentrate transportation costs are found to be associated with the less-accessible northern deposits;

- as shown in table 31, the foregoing factors tend to cancel out. Consequently, minesite revenue per tonne of ore is estimated to be the same for the territories and the provinces;

- unit capital expenditures and unit production costs are similar for economic deposits in northern and southern Canada. As discussed in chapter 4, this is remarkable in view of the much higher remoteness costs borne by economic deposits in the north. The impact of these remoteness costs on the viability of base metal deposits was previously demonstrated in table 17. A clue to explaining the similarity in costs shown in table 31 may be found in the lower mining losses associated with the northern deposits. It appears that the relative closeness to surface of economic deposits in the north enables the application of mining methods which are sufficiently lower in cost as compared to the typically deeper underground mining situations in the south, to offset the higher remoteness costs associated with their geographic location.

The end result of the appraisal of cash flow components is that before-tax cash flow per tonne of ore in the territories is just as attractive as in the provinces. The lower quality of base metal ores in the north in terms of their remote location is essentially offset by their higher quality in terms of closeness to the surface. This explains the similarity of the overall economic return characteristics in the two study areas.

Figure 13 compares the metal product mix recoverable from the economic deposits discovered in the territories and provinces. Zinc predominates in the north. As mentioned, the high proportion of zinc and the associated production of zinc concentrate explains the comparatively high smelting and refining charges in the north. The large zinc and lead shares also imply that a relatively large proportion of the northern discoveries are sediment-hosted massive sulphide deposits.

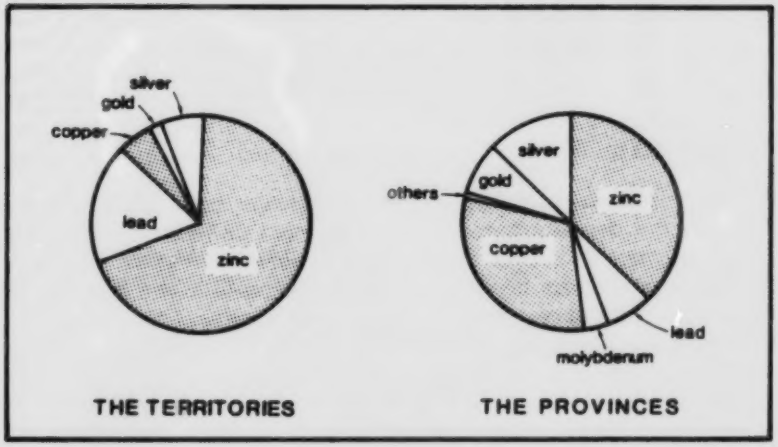

Figure 13. Metal Product Mix for Economic Deposits in the Territories and Provinces

The metal product mix in the provinces is found to be more balanced. Zinc is once again important but its contribution is matched by copper. Silver, gold, lead, and molybdenum also play important roles. This diversified metal product mix reflects the parts played by the economic porphyry and volcanic-associated deposits.

Return Characteristics by Deposit Type

While the return characteristics of economic base metal discoveries in northern and southern Canada are found to be similar for all economic deposits taken together, chapter 7 shows that the comparative returns are a function of geological region. Thus, within the shield region the return characteristics of economic discoveries in the provinces are found to be more attractive than those in the territories. Within the cordilleran region, on the other hand, economic discoveries in the territories are found to be superior to those in the provinces.

Each geological region contains a variety of deposit types. To compare the return characteristics of economic discoveries in another geologically consistent way, this section groups the economic discoveries into deposit-type categories: volcanic-associated massive sulphide deposits, sediment-hosted massive sulphide deposits, porphyry deposits, and "other" deposits. Assessments are made for each of the first three categories. Brief descriptions of the deposit types are given in appendix V.

The average return characteristics for economic discoveries are presented in table 32. Table 33 shows the unit cash flow components for economic discoveries within each deposit-type category. The average metal product mixes are illustrated in figure 14.

The following results can be discerned:

- sediment-hosted economic deposits are shown to predominate in northern Canada, while volcanic-associated deposits are most strongly represented in the south. Economic porphyry deposits also play a significant role in the provinces;

- the influence of economic porphyry deposits on return characteristics for Canada overall and, more importantly, for the provinces, is indicated by their extremely large size (table 32) and very low grade, as reflected by the gross in-situ value per tonne of ore (table 33);

- the average return characteristics for volcanic-associated deposits in southern Canada, in terms of net present value and rate of return indicators, are shown to be more attractive than in the territories. This finding is consistent with the comparative shield region results in chapter 7. Most of the volcanic-associated discoveries occur in the shield;

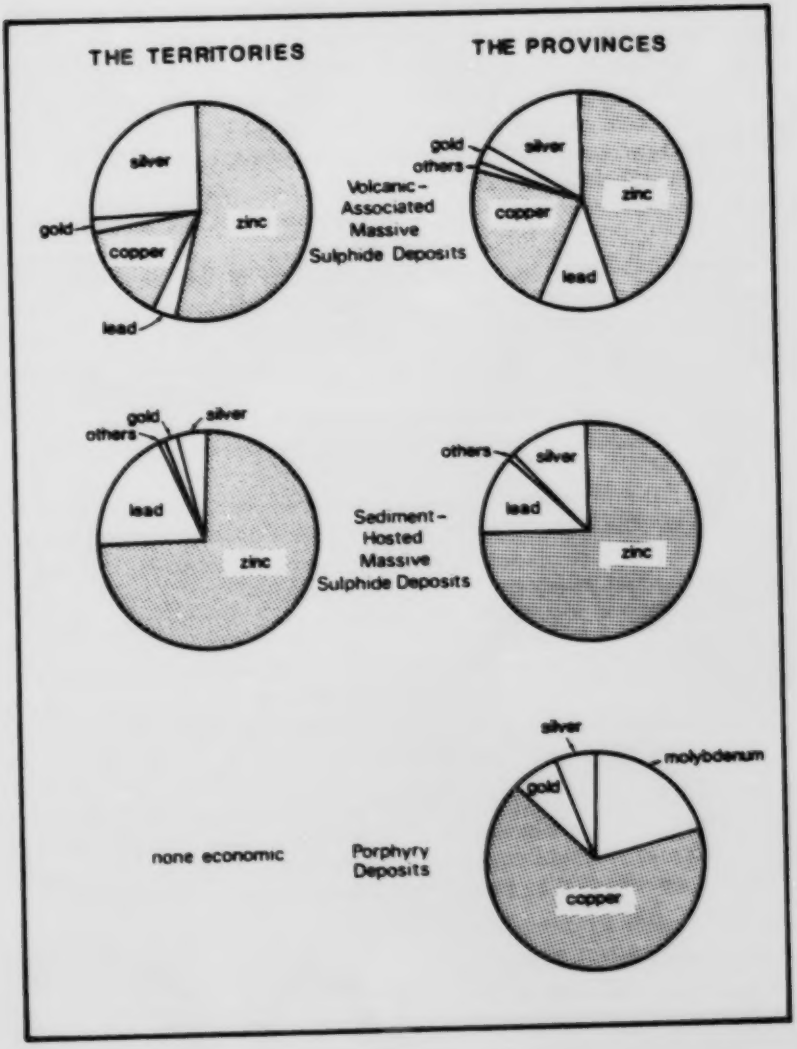

Figure 14. Metal Product Mix for Economic Deposits by Type

- economic sediment-hosted deposits in the territories are shown to offer much more attractive return characteristics than in the south. The less favourable economic characteristics of sediment-hosted deposits in the provinces combined with the low profitability of the porphyry ores helps to explain the comparative cordilleran region findings. Most of the sediment-hosted deposits in the provinces, and all of the porphyry deposits, occur in the cordilleran region. While the majority of economic sediment-hosted deposits in the north are located in the cordilleran region, a notable contribution is also made by the relatively profitable deposits which occur in the platform region;

- volcanic-associated deposits, particularly those found in the north, are shown to have much higher grades than the other two deposit types. While the before-tax cash flow per tonne of ore in the territories is substantially higher than in the south, the deposits are much smaller. The return characteristics per economic deposit in the north are as a result shown to be somewhat less attractive than in the provinces;

- although the grade and before-tax cash flow advantages of sediment-hosted deposits in the territories are not as great as for the volcanic-associated grouping (table 33), when combined with the larger average size of discoveries in the north, their return characteristics are found to be much more attractive than for sediment-hosted discoveries in the provinces (table 32);

- when economic deposits are grouped by type, there is more consistency between the metal product mixtures recoverable from the northern and southern discoveries (figure 14 versus figure 13).

One question remains: which area has the most favourable mix of deposit types? Canada-wide assessments of the return characteristics of economic deposits by type are presented in table 34. The volcanic associated and sedimentary-hosted groupings are shown to offer attractive and comparable returns. Economic porphyry deposits, as we have seen, are typically more marginal. With reference to the overall Canadian averages, it may be surmised that "other" types of deposit are relatively small in size and probably much less profitable on average than the vol-

Table 32

AVERAGE RETURN CHARACTERISTICS OF ECONOMIC DEPOSITS BY TYPE IN THE TERRITORIES AND PROVINCES

Characteristic	Volcanic-Associated Deposits		Sediment-Hosted Deposits		Porphyry Deposits	
	The Territories	The Provinces	The Territories	The Provinces	The Territories	The Provinces
Number of economic discoveries	4	47	23	4	–	11
Average deposit size (million tonnes)	6	17	30	12	–	298
Net present value per economic deposit (start of development, $ million)	229	309	280	64	–	357
Rate of return (development and production phases, percent)	43	52	41	16	–	23

Table 33

AVERAGE CASH FLOW COMPONENTS OF ECONOMIC DEPOSITS BY TYPE IN THE TERRITORIES AND PROVINCES ($ per tonne of ore)

Component	Volcanic-Associated Deposits		Sediment-Hosted Deposits		Porphyry Deposits	
	The Territories	The Provinces	The Territories	The Provinces	The Territories	The Provinces
Gross in-situ value	337	246	188	169	–	29
Less: Mining losses	55	33	16	34	–	1
Milling losses	28	40	21	17	–	4
Smelting and refining charges	68	55	58	46	–	4
Concentrate transportation costs	20	9	16	5	–	1
Revenue at minesite	166	109	77	67	–	19
Less: Preproduction capital expenditures	21	15	9	10	–	2
Production costs	58	43	30	37	–	9
Before-tax cash flow	87	51	38	20	–	8

canic-associated and sediment-hosted categories. The latter two categories account for about two thirds of the significant base metal deposits discovered to 1977 in both the territories and the provinces. While the proportions of each type differ, this limited evidence suggests that the mixtures of deposit types found in northern and southern Canada have similar economic potential.

Table 34

CANADA-WIDE ASSESMENT OF AVERAGE RETURN CHARACTERISTICS OF ECONOMIC DEPOSITS BY TYPE

Characteristic	Volcanic-Associated Deposits	Sediment-Hosted Deposits	Porphyry Deposits	Total
Net present value per economic deposit (start of development, $ million)	327	382	357	266
Rate of return (development and production phases, percent)	53	50	23	36

Comparison of Returns for Pre-1946 and 1946-77 Economic Discoveries

To provide a more complete picture of the return characteristics of economic deposits, pre-1946 discoveries are now included in the analysis.[2] Overall economic indicators per economic deposit are compared in table 35. Table 36 shows the cash flow breakdowns for these discoveries. The average metal product mix recoverable from economic deposits discovered prior to 1946 and during the 1946-77 period are illustrated in figure 15.

[2] This makes no difference in the territories since the one base metal deposit discovered before 1946 is uneconomic for the assumed conditions.

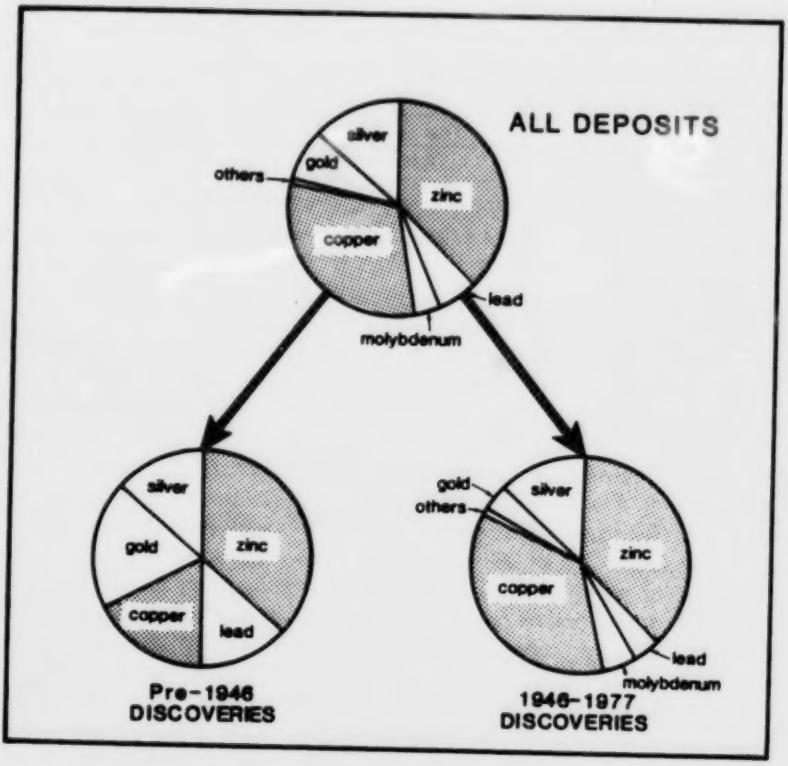

Figure 15. Time Trend in Metal Product Mix in the Provinces

All economic deposits in the territories have been discovered during the 1946-77 period. In the provinces, average return characteristics for economic deposits discovered before 1946 are found to be more attractive than for those made during 1946-77. While the average size of economic deposits in southern Canada increases by a factor of three times, reflecting once again the influence of large prophyry discoveries, both the average rate of return and the net present value per economic discovery indicators highlight the superior quality of the base metal deposits discovered prior to 1946.

Table 35

COMPARISON OF RETURN CHARACTERISTICS FOR PRE-1946 AND 1946-77 ECONOMIC DISCOVERIES

	The Territories			The Provinces		
Characteristic	Pre-1946	1946-77	Total	Pre-1946	1946-77	Total
Number of economic discoveries	–	29	29	17	71	88
Average deposit size (million tonnes)	–	26	26	21	60	52
Net present value per economic deposit (start development, $ million)	–	263	263	564	268	325
Rate of return (development and production phases, percent)	–	39	39	81	35	42

Table 36

COMPARISON OF AVERAGE CASH FLOW COMPONENTS FOR PRE-1946 AND 1946-77 ECONOMIC DISCOVERIES ($ per tonne of ore)

	The Territories			The Provinces		
Component	Pre-1946	1946-77	Total	Pre-1946	1946-77	Total
Gross in-situ value	–	203	203	240	193	202
Less: Mining losses	–	21	21	36	27	29
Milling losses	–	21	21	37	30	31
Smelting and refining charges	–	57	57	46	42	42
Concentrate transportation costs	–	17	17	6	7	7
Revenue at minesite	–	87	87	115	87	93
Less: Preproduction capital expenditures	–	11	11	13	12	13
Production costs	–	34	34	38	36	36
Before-tax cash flow	–	42	42	64	39	44

Explanations for the relative attractiveness of the initial economic discoveries can be deduced from the cash flow components per tonne of ore (table 36). In particular, average ore grades for the pre-1946 economic deposits, as reflected by the gross in-situ value per tonne of ore, are significantly higher than for the more recent discoveries. Although higher mining and milling losses partially offset this advantage, the before-tax cash flow per tonne is also significantly greater, translating into the better average return characteristics for the pre-1946 discoveries shown in table 35.

The economic superiority of the earlier economic discoveries in the provinces is attributable, in part, to their relatively high precious metal content, as illustrated in figure 15.[3] The lower proportion of copper and the absence of molybdenum in the pre-1946 discoveries is explained by the fact that, at that time, porphyry deposits were not of economic interest.

These findings help explain the similarity of return characteristics for economic discoveries in northern and southern Canada during the 1946-77 period. The similarity can now be viewed in relation to the better return characteristics for pre-1946 discoveries in the provinces. The comparability of north-south return results appears to be partly attributable to the more mature state of base metal mining in the provinces during the study period. The quality of base metal deposits discovered in the territories during the 1946-77 period is comparable to the geological characteristics of the pre-1946 economic discoveries in the provinces. This reinforces the assertion made in chapter 6 that the base metal exploration and discovery experience in the territories lags at least 20 years behind southern Canada.

Summing Up

The main findings of our detailed examination of the return characteristics of economic deposits in northern and southern Canada are as follows.

[3] The relatively high gold content of the pre-1946 discoveries is linked to the large proportion of these deposits found by prospecting (93 percent, as shown earlier in table 24). A traditional prospecting method is to look for indications of gold in river gravels. Gold-rich base metal deposits were in some cases discovered by tracing these gold indications back to their source.

1. The higher cost of developing and mining base metal ores in northern Canada due to their less-accessible geographical location is essentially offset by the higher quality of the ores in terms of closeness to the earth's surface.

2. While the average return characteristics of volcanic-associated deposits in the provinces are shown to be more attractive than those found to date in the territories, sediment-hosted deposits in the north are found to be superior to those discovered in southern Canada. The mixtures of deposit types revealed in the territories and provinces appear to be similarly favourable.

3. The returns for economic deposits discovered in the provinces before 1946 are superior on average to those made during the 1946-77 period. Ore grades (particularly precious metals content) are significantly higher for the earlier discoveries. The number and quality of base metal deposits discovered in the territories to 1977 appears to be comparable to the pre-1946 experience in southern Canada.

9. EFFECT OF MINING TAXATION ON COMPARATIVE NORTH-SOUTH RESULTS

Chapters 4 to 8 have examined the potential, before-tax value of base metal mining in Canada with particular reference to differences in supply characteristics existing between the territories and provinces. It is now appropriate to evaluate these assessments from the viewpoint of mining companies contemplating investment in base metal exploration and development. For this purpose, the Canadian mining taxation systems existing in 1983 are imposed on the potential value assessments, and measures of investment incentive are derived. The combined effect of three aspects of taxation are analyzed here: federal corporate income tax, provincial and territorial corporate income tax, and provincial and territorial mining tax (including royalties). A description of the tax regimes applied is given in appendix VI.

Taxation Considerations

Inflation

The existence of inflation complicates the evaluation of mining taxation effects, for two reasons. First, the write-off of capital costs for tax purposes in such forms as depreciation allowance, processing allowance, and earned depletion allowance is normally only permitted over a future period of time. Tax allowances are taken against the current money income realized in those future time periods. Second, the amount which can be written off is limited to the actual capital costs incurred. Consequently, inflation reduces the real constant-money benefits of tax write-offs. Inflation thereby lowers investment incentive and increases government tax revenues in real terms. The higher the rate of inflation, the stronger these effects will be.

It is therefore important to take inflation into account when assessing the after-tax value of base metal mining. An 8-percent per year general rate of inflation is assumed for this purpose.

Exploration Expenditures

The Canadian mining taxation systems outlined in appendix V permit the "expensing" of exploration expenditures against current income as they are incurred.[1] This study does not consider the carry-forward of exploration expenditures for write-off against production income from economic deposits. Larger organizations are assumed to have sufficient income from other domestic mine sources to be able to deduct exploration expenditures as they are incurred, receiving tax credits immediately. Smaller enterprises are assumed to have no existing income, and therefore receive no tax benefit from their exploration expenditures.

The base case views exploration from a larger company perspective, assuming that all exploration expenditures are expensed for tax purposes.[2] To represent the case of an independent exploration organization with no sources of income, a 0-percent expensing variant is considered.

Development and Production Phases

Mining taxation allowances for the development and production phases may be taken either on an individual project basis or on an integrated company basis. With the individual project basis of taxation, allowances for the development and production phases may be taken only against production income from the project. It is thus assumed that the mining company has no existing sources of income. By "integrated company" we mean a mining company with existing sources of income from other activities. With the integrated company basis of taxation, allowances for the development and production phases may be written off as rapidly as possible against this existing income stream. The tax credits realized on an integrated company basis will, therefore, be more immediate than on an individual project basis.

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1 When we say that exploration expenditures are "expensed" for tax purposes, we mean they are deducted from a company's income in the year expended for purposes of computing taxable income. This, for example, is the same way operating costs are treated for tax purposes.

2 With flow-through shares, the tax treatment of exploration expenditures made by smaller enterprises is in effect similar to that of larger companies except that the tax credit from the write off is realized by the purchaser of the shares rather than by the company itself.

The base case assumes that taxation is on an individual project basis.[3] Taxation on an integrated company basis is considered as a variant.

Canada

The base case conditions, to which other results are compared, include those specified in chapter 4 for the Canada-wide assessment of potential value. In addition, the following taxation conditions, discussed above, are embodied in the base case:

- 1983 federal, provincial and territorial mining taxation systems;
- 8-percent general rate of inflation;
- 100-percent expensing of exploration expenditures;
- individual project basis of taxation for development and production phases.

Under these conditions, the number of economic deposits is reduced from 100 to 84. Thus, 16 of the potentially economic deposits are rendered uneconomic by the taxation systems existing in 1983. This highlights an important inefficiency in Canadian taxation policy.

The cost and revenue characteristics of these 84 economic deposits are used to assess the time distribution of average after-tax cash flows for an economic deposit. The average cash flow results are presented in figure 16 and summarized as follows.

[3] We are endeavouring to analyze the effects of taxation on an industry which comprises companies in a wide range of tax positions. Development and production phase tax allowances may be deducted from any Canadian income earned by the company for federal corporate income tax purposes, against any income within the province in which the investment is carried out for provincial income tax purposes, and against mining income earned within the province in which the investment is made for provincial mining tax purposes. Thus, even the largest companies are often unable to take full advantage of the integrated company tax provisions.

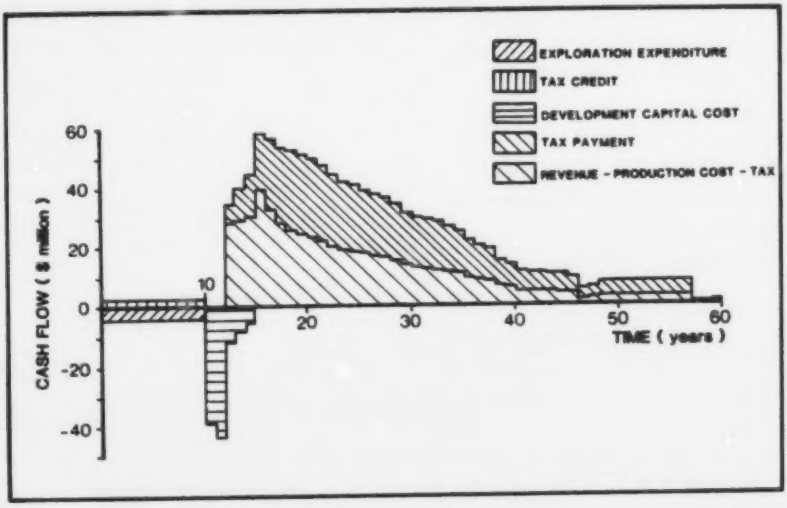

Figure 16. Time Distribution of Average Cash Flows for an Economic Deposit in Canada After Tax

Exploration: about 10 years, with average before-tax exploration expenditures of $40 million per economic deposit. Tax credits totalling $26 million are realized from these expenditures, resulting in an average after-tax cost per economic discovery of $14 million.

Development: up to 5 years, with an average preproduction capital cost of $109 million per economic deposit.

Production: up to 48 years, with annual cash flows which vary as shown in figure 16. Average values per economic deposit are:

- revenue, $1901 million;
- production cost, $716 million;
- federal corporate income tax, $283 million;
- provincial corporate income tax, $103 million;
- provincial mining tax, $203 million.

Thus, on average, the after-tax cash flow associated with an economic deposit is (1901 -14 -109 -716 -283 -103 -203) = $473 million.

Table 37 presents after-tax expected value assessments derived from this average time distribution of cash flows. As already mentioned, 16 deposits which are potentially viable become uneconomic as a result of the 1983 tax systems. The average exploration expenditure required to find and delineate an economic deposit, $24 million potentially at the start of exploration, is reduced to approximately $9 million on an after-tax basis. However, the average return from an economic deposit is also reduced, from $139 to $62 million. Overall, the after-tax expected value per economic discovery is about $53 million. The economic incentive for investment in base metal supply is also reflected by the 18-percent

Table 37

AFTER-TAX EXPECTED VALUE ASSESSMENTS IN CANADA

Characteristic	Canada
Number of economic discoveries:	
Potential	100
After tax	84
Average exploration expenditure (E, $ million):	
Potential	24
After tax	9
Average return (R, $ million):	
Potential	139
After tax	62
Expected value (EV, $ million):	
Potential	115
After tax	53
Rate of return (percent):	
Potential	19
After tax	18
Share of actual value (percent):	
Mining company's share	45
Governments' share	55

after-tax discounted cash flow rate of return, as compared to the 19-percent potential rate of return (assessed in chapter 4) and the 8-percent cost of capital. These results suggest that the investment incentive provided for base metal exploration in Canada under 1983 taxation policies, assuming expected value prices, and considering the risks involved, is not unattractive overall.

The incidence of taxation can be illustrated by comparing the mining company's share and the governments' share of the actual value realized from base metal supply.[4] Total tax payments are found to be equivalent to 55 percent of the actual value realized. The remaining 45 percent is realized by mining companies in the form of after-tax cash flows.

North-South Comparison

The Canada-wide assessment is partitioned here into our two study areas - the territories and the provinces. Otherwise, the evaluation conditions are the same as specified for the base case.

After-tax expected value assessments are compared in table 38. The impact of taxation is shown to be more severe in southern Canada. Of the 16 deposits rendered uneconomic by the tax system, 15 are located in the provinces. The reduction in the expected value indicators is also proportionally greater than in the territories. These differing taxation effects arise from two factors. First, as indicated in chapter 5 (figure 11), there is a higher proportion of smaller, more marginal economic deposits in southern Canada. The negative impact of any taxation system is thus potentially greater. Second, the effective rates of taxation are higher on average in the provinces than in the territories.

[4] The actual value realized is defined as the sum of the after-tax expected value per economic discovery (the mining company's share) and the net tax payments evaluated as a present value amount at 8 percent discounted back to the start of exploration (the governments' share).

Table 38

AFTER-TAX EXPECTED VALUE ASSESSMENTS IN THE TERRITORIES AND PROVINCES

Characteristic	The Territories	The Provinces
Number of economic discoveries:		
Potential	29	71
After tax	28	56
Average exploration expenditure (E, $ million):		
Potential	10	28
After tax	5	10
Average return (R, $ million):		
Potential	210	117
After tax	114	46
Expected value (EV, $ million):		
Potential	200	89
After tax	109	36
Rate of return (percent):		
Potential	32	16
After tax	26	15
Share of actual value (percent):		
Mining company's share	53	42
Governments' share	47	58

The incidence of taxation is portrayed in figure 17. Total tax payments in the territories are shown to be equivalent to 47 percent of the actual value realized from base metal mining as compared to 58 percent in the provinces. Conversely, the mining company's share, 53 percent in the north, is only 42 percent in southern Canada.

The components of the tax revenues collected are shown in figure 18. Provincial or territorial mining taxes, the main reason for the differing incidence of taxation, account for about 27 percent of total tax payments in the territories as compared to 37 percent in the provinces. The provincial income tax share is also somewhat higher in southern Canada at 18 percent, as compared to 16 percent in the north. Federal corporate income tax accounts for the balance of tax revenues, 57 percent of total payments in the territories and 45 percent in the provinces.

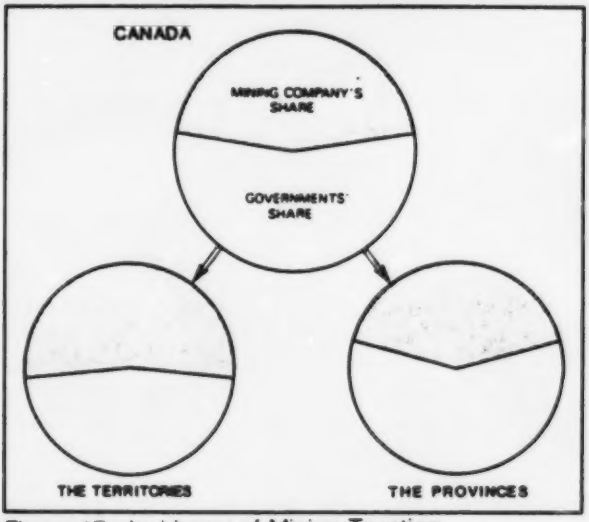

Figure 17. Incidence of Mining Taxation

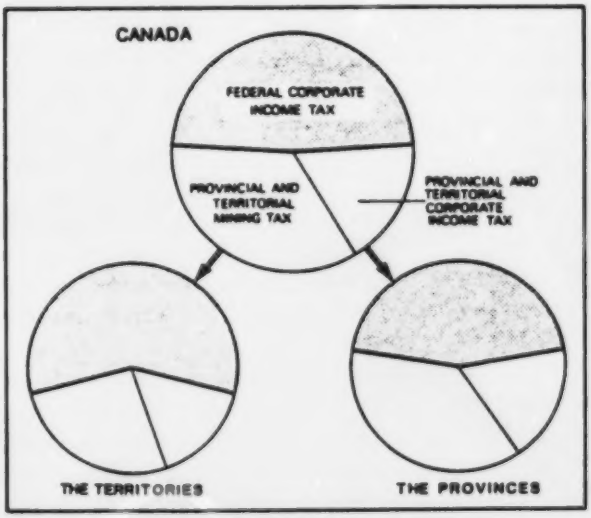

Figure 18. Components of Mining Taxation

Metal Price Variants

Table 39 presents after-tax assessments as a function of metal prices. The expected value and rate of return results show that, while the incentive to invest in base metal mining in northern Canada would remain marginally economic at lower-limit prices, results become uneconomic on average in the provinces. On the other hand, given upper-limit price conditions, there would be a strong economic incentive for base metal investment throughout Canada.

It is interesting to note how the incidence of taxation changes as a function of commodity prices. As prices are reduced from upper-limit to expected levels there is little variation, the governments' share of the actual value increasing from 46 to 47 percent in the territories, and declining from 59 to 58 percent in the provinces. There are marked differences, however, as prices are lowered further from expected to lower-limit levels. As the economic margin of investment is approached in the north, the governments' share falls from 47 percent to 22 percent. In southern Canada, government assumes 71 percent of the economic loss incurred at lower-limit market prices. These results indicate that mining taxation systems throughout Canada tend to provide a considerable degree of relief for marginal and uneconomic investment conditions.

Small and Large Company Tax Variants

The after-tax incentive to invest depends in part on the degree to which a mining company can take advantage of the exploration and development write-off provisions in the taxation system. This is determined by the availability of income, generally a function of company size. The base case assumes a mixture of large and small company activity. Here, we consider two other tax variants.

1. Small company: 0-percent expensing of exploration expenditures; individual project basis of taxing mine development and production.

2. Large company: 100-percent expensing of exploration expenditures; integrated company basis of taxing mine development and production.

Table 39

AFTER-TAX EXPECTED VALUE ASSESSMENTS AS A FUNCTION OF METAL PRICE

	Lower-Limit Prices		Upper-Limit Prices	
	The Territories	The Provinces	The Territories	The Provinces
Number of economic discoveries:				
Potential	11	17	36	123
After tax	8	16	35	111
Average exploration expenditure (E, $ million):				
Potential	22	48	8	19
After tax	13	15	4	8
Average return (R, $ million):				
Potential	31	10	426	254
After tax	17	3	234	110
Expected value (EV, $ million):				
Potential	9	-38	418	235
After tax	4	-12	230	102
Rate of return (percent):				
Potential	10	4	48	29
After tax	9	5	40	25
Share of actual value (percent):				
Mining company's share	78	29	54	41
Governments' share	22	71	46	59

After-tax assessments for these tax variants are compared in table 40. The expected value and rate-of-return results illustrate the more favourable tax position of large companies relative to small enterprises. In comparing the potential value and after-tax results, it is apparent that the benefits of large company taxation impact more strongly on the rate-of-return criterion. The explanation for this is that in the cases considered in table 40, the rate of return is higher than the 8-percent cost of capital used in assessing the expected value. Since the implicit discount rate used in evaluating the rate of return is higher, the discounted equivalent of the tax credits realized during exploration and development has a stronger weighting, relative to the discounted tax payments from the mine production phase. For large company taxation, the discounted tax credits can in fact exceed the discounted tax payments, raising the after-tax rate of return above the potential value. This indeed is the case for the provinces, the rate of return increasing from 16 to 17 percent.

The difference in investment incentive between small and large company taxation of base metal mining appears to be more pronounced in the provinces, particularly with respect to the expected value measure. This is mainly a result of the larger number of deposits in southern Canada which are close to the economic margin. The number of economic discoveries after tax is therefore more sensitive to the company's tax position than is the case in the territories. When large company and small company taxation results are compared (table 40), the number of economic deposits increases from 28 to 30 in the territories, and from 56 to 71 in the provinces. Consequently, the relative improvements in expected value and rate of return are greater in southern Canada than in the north.

Table 40

AFTER-TAX EXPECTED VALUE ASSESSMENTS FOR SMALL AND LARGE COMPANY TAX VARIANTS

	Small Company		Large Company	
	The Territories	The Provinces	The Territories	The Provinces
Number of economic discoveries:				
Potential	29	71	29	71
After tax	28	56	30	71
Average exploration expenditure (E, $ million):				
Potential	10	28	10	28
After tax	10	32	5	8
Average return (R, $ million):				
Potential	210	117	210	117
After tax	114	46	114	50
Expected value (EV, $ million):				
Potential	200	89	200	89
After tax	104	14	109	42
Rate of return (percent):				
Potential	32	16	32	16
After tax	23	9	30	17

Summing Up

The impact of taxation on investment incentive is shown to be more onerous in southern Canada than in the territories. For base case conditions, 58 percent of the actual value realized from base metal mining in the provinces would be paid to government in direct profit-based taxes as compared to 47 percent in the territories. Differences in provincial and territorial mining tax rates are the main reason for this comparative result. The incidence of taxation is a direct function of projected metal prices, the tax burden easing as the level of prices is reduced towards the economic margin of investment. The difference in investment incentive between the tax treatment of small companies and large companies is found to be more pronounced in the provinces than in the territories.

10. CONCLUSIONS

Setting

The study compares the economic potential of mineral exploration and development in less-accessible frontier areas of the territories, the Canadian north, with more-established mining regions in the provinces. The main question is - does "more remote" necessarily mean "less economic"? We are interested in the implications of study results for mining company planning and government policy formulation.

The assessment focuses on "base metal" resources, defined for study purposes to include copper, zinc, lead, and molybdenum deposits with their associated byproducts, mainly gold and silver. In spite of adverse market conditions during the 1982-86 period, base metal supply remains of central importance to the Canadian mineral economy. This sector makes an essential contribution to regional and northern development, and is sensitive to location and the availability of infrastructure. Base metal supply is therefore an appropriate grouping for the north-south comparison we are making.

Theoretical Rationale

A process of mineral-led exploration and development of regions remote from existing population centres and infrastructure continues to be a vital force in pushing back the Canadian frontier. Like all investment decisions, the choice between mining in frontier areas and mining in established districts is based on a balancing of incremental costs and benefits. The locational costs of exploration and development in remote areas are higher. On the other hand, a continual depletion of ores is taking place at operating mines in established districts. As the higher-quality mineral resources in these traditional areas are exhausted, there is increasing benefit to be gained by directing investment towards the higher-quality resources still awaiting discovery in frontier areas.

This evolutionary process is also shaped by differences in inherent geological potential among areas, technological advances, the unexpected discovery of high-quality deposits in established districts, and the dynamics of international mineral markets. Nevertheless, it is the fixed

size, variable quality, and exhaustible nature of mineral deposits which ultimately push back the extensive margin of mineral exploration and development. At the mining frontier, the incremental costs and benefits of investment theoretically should balance.

Methodology and Data Base

The economic potential of base metal exploration and development in the territories and provinces is assessed using several expected value and risk criteria. The evaluation is carried out on a potential value basis and on an after-tax basis.

The potential value of base metal mining is initially evaluated for Canada overall, providing a standard of comparison for more specific assessments in the territories and provinces. Appraisals of exploration expenditures and the returns from economic discoveries are based on a historical documentation of all significant base metal deposits discovered during the 32-year period 1946-77. A comparison is also made of the return characteristics of pre-1946 discoveries with those of deposits found during the study period.

Canada-wide exploration expenditures associated with base metal deposits discovered during the 1946-77 period are estimated to total $3.4 billion.[1] The Yukon and Northwest Territories, comprising 40 percent of Canada's landmass, accounted for only 10 percent of this investment. The territories' share, however, increased from 4 percent to 17 percent during the study period.

A total of 291 base metal deposits discovered in Canada to 1977 which could possibly satisfy minimum acceptable economic conditions are included in the assessment. Of this total, 62 deposits were discovered prior to 1946, the remaining 229 discoveries occurring during the 1946-77 period. 20 percent of these deposits were discovered in the territories. The north's share of discoveries increased from 12 percent to 38 percent during the study period.

The historical exploration expenditures and actual deposit-specific information for each of the 291 base metal discoveries form the main part of the study data base. For planning purposes, this historical record is placed in the context of current outlook conditions. Thus, a central as-

[1] Money values are expressed throughout in constant 1983 Canadian dollars.

pect of the evaluation is to determine which of the discoveries made to 1977 would be economic under today's conditions.

For this purpose, general market estimates of future metal prices and smelter payments are combined with estimates for individual deposits of ore reserves, capacity, costs, and recovery factors. The deposit-specific estimates, based on the historical record, attempt to portray how each discovery would look today if it was awaiting development. Cash flow estimates for those deposits that on evaluation satisfy minimum acceptable conditions are integrated with exploration expenditure estimates to assess the economic potential of base metal mining in the territories and provinces.

The following aspects of infrastructure development are fully costed in our assessment:

- mine access roads to connect with regional networks;
- housing and single-worker accommodation;
- townsite and camp amenities;
- facilities for fly-in work programs;
- power generating and transmission facilities.

The one item of infrastructure not included in the appraisal is the capital cost of regional roads required where presently undeveloped deposits are remote from existing all-weather road and rail facilities.[2] The study assumes that government, as in the past, will provide regional roads not just in the north but throughout Canada when they can be justified for economic development.

In addition to the cost of infrastructure development, capital and operating cost premiums are estimated for each deposit as a function of its location.

Findings

The main conclusion of the study is that the economic attractiveness of base metal mining potential in the Yukon and Northwest Territories is significantly greater than in southern Canada. For the base case condi-

[2] The most important case in this regard pertains to base metal deposits in the northeast Mackenzie district of the Northwest Territories.

tions specified in the assessment, the following potential value results are obtained:

- expected value per economic discovery of $200 million in the territories compared to $89 million in the provinces;
- expected rate of return on investment of 32 percent in the territories compared to 16 percent in the provinces.

The general validity of these results is tested by evaluating the sensitivity of the economic potential of base metal supply in the two study areas to wide ranges of specified variations in key study parameters above and below their assumed base case values. The sensitivity analysis in all cases confirms that the potential value of base metal mining in the territories is significantly greater than in southern Canada.

The economic viability of base metal supply in the provinces is found to be more sensitive to the specified variations in assumed conditions than the economics of supply in the north. This is mainly explained by the greater proportion of marginal economic deposits discovered in southern Canada.

Distinct mixtures of geological regions occur in the territories and the provinces. To further examine the relative economic potential of the territories, comparative north-south assessments are also made within each of the two major geological provinces - the shield and cordilleran regions. Both sets of results are consistent with the main study finding. The difference in potential value is particularly pronounced in the cordilleran region. The relative attractiveness of the north within the shield region is more marginal, and also more uncertain in view of the small sample size of experience to date in the territories.

Following on from the appraisal by geological region, a comparison is made of the return characteristics of economic deposits grouped by deposit type in the territories and provinces. Here the evidence is mixed. While the economic returns of sediment-hosted deposits in the territories are found to be superior to those discovered in the south, volcanic-associated deposits in the provinces are shown to be superior to those found to date in the north.

All of the results discussed to this point are made on a before-tax basis. The combined effect of three aspects of Canadian taxation - federal corporate income tax, provincial and territorial corporate income tax, and provincial and territorial mining tax - is also analyzed. The impact of taxation on investment incentive is found to be more severe in the provinces than in the territories. For example, given the base case

conditions specified in the evaluation, 58 percent of the actual value realized from base metal mining in the provinces would be paid to government in direct profit-based taxes as compared to 47 percent in the territories. From a mining company viewpoint, this enhances the relative favourability of base metal mining potential in the Yukon and Northwest Territories.

Explanation of Results

The lower incidence of taxation in the north is a consequence of relatively low territorial tax rates. A more fundamental question arises with respect to the potential value results - why is the economic attractiveness of base metal supply potential in northern Canada significantly greater than in the provinces?

In seeking to explain the comparative differences, the potential value of base metal mining is broken down into its two main components:

- the average exploration expenditure per economic discovery;
- the average return from development and production for an economic deposit.

Study results show that average discovery costs are much lower in the territories. Under base case conditions, for example, the average exploration expenditure per economic discovery is found to be $12 million as compared to $43 million in the provinces. The difference is explained by three factors:

- deposits are relatively easy to find in the north because bedrock exposure is better and the land's surface is more readily observable;
- exploration is more efficient in the north due to a smaller number of active companies and less duplication of effort;
- depletion tends to be more advanced in the provinces resulting in a smaller proportion of undiscovered deposits and deeper, more costly exploration programs.

The return potential for economic deposits in the territories is found to be comparable on average to the returns offered by economic discoveries in southern Canada, as illustrated by the base case results. The net present value for an economic discovery at the start of development

averages $263 million in the territories and $268 million in the provinces. The average rates of return are 39 percent and 35 percent respectively.

The high cost premiums associated with developing and operating mines in the north are fully accounted for in making these return assessments. We find that the economic deposits discovered in the territories to date are of a relatively high quality, particularly in terms of their closeness to the earth's surface, permitting low-cost open pit and shallow underground mining methods to be applied. While base metal deposits in the territories are remote in a two-dimensional surficial or geographical sense, deposits in the provinces are increasingly remote in the third dimension - depth below the surface. Study results show that the costs associated with these two types of remoteness cancel out. The return characteristics of economic base metal deposits in northern and southern Canada are therefore similar.

Summing up, discovery costs in the territories are much lower and average returns are comparable to those which characterize base metal exploration and development in the provinces. Taken together, the economic potential of base metal mining in the north is significantly greater than in southern Canada.

The overriding benefit of base metal exploration and development in the north is not, however, one of physical advantage. Rather, it is explained by the economic forces and time trends that underlie the phenomenon of pushing back the mining frontier. Study results demonstrate that base metal mining in the territories and the provinces are at quite different stages of maturity.

The base metal supply process in the north lags at least 20 years behind southern Canada. Experience in the territories during the 1946-77 period is found to be similar to base metal exploration and development in the provinces prior to World War II. For example, prospecting accounts for almost two thirds of the base metal deposits discovered in the north. Also, the quality of these discoveries is shown to be comparable to deposits discovered prior to 1946 in the provinces.

This time lag between base metal activities in the provinces and in the territories is put forward as the main reason for the superior economic potential of northern Canada. If this explanation and the comparative findings on which it is based are valid, a key question for corporate planning and government policy is - how long will this situation last? We cannot answer this question in a definitive way. However, simply based on the respective sizes of the two study areas, we would expect the existing time lag to continue to lengthen until the levels of base metal

exploration, development, production, and depletion in the territories approach 40 percent of the Canada-wide totals. Even in the mid-1980s, at least 85 percent of base metal mining activities is concentrated in the provinces. Therefore, it will no doubt take many years for the time lag to return to its present length. In the meantime, we expect the economic potential of base metal mining in the territories relative to the provinces to be further enhanced.

Recent Trends in Base Metal Exploration

Base metal exploration trends in Canada since 1977 are revealing. Exploration expenditures were at a high level until 1981, averaging about $150 million per year. Drastic cuts in base metal budgets then followed in response to the recession in world markets and the rush into gold exploration. By 1986, less than $75 million per year was being expended on exploration for base metal deposits in Canada.

The successive reductions in base metal exploration which have occurred appear to follow a systematic pattern:

- more remote programs have tended to be sacrificed first;
- an increasing share of the exploration activity is being undertaken by the base metal producing companies;
- exploration programs have mainly concentrated in the vicinity of operating mines to protect the viability of existing assets.

Consequently, a greater proportion of base metal exploration activity is taking place within the provinces. The share of Canadian expenditures accounted for by the Yukon and Northwest Territories fell from more than 20 percent in the late-1970s to less than 10 percent in the mid-1980s. Even in the north, most of the activity became focused on targets around existing base metal operations.

Several notable base metal deposits have been discovered as the successful result of exploration carried out since the end of our study timeframe. Economic discoveries during the 1978-86 period include the HW orebody on Vancouver Island; Duck Pond in the Buchans area; Ansil, Isle Dieu, Norita East, and Gaspé E in Quebec; Winston Lake in Ontario; and the Callinan deposit at Flin Flon. Considering the pattern of base metal exploration at this time, it is not surprising to find that six of these eight discoveries are close to existing mining operations, while the other

two, Duck Pond and Winston Lake, are close to former base metal mines. This recent experience demonstrates that good discovery possibilities continue to exist in established mining districts with long, intensive exploration histories.

There is no question about the quality of these discoveries or their value to the mining companies and communities concerned. However, after adding other significant discoveries to the list, the number of base metal deposits found during the 1978-86 period is still remarkably small when compared to total exploration expenditures in excess of $1 billion. Consequently, the potential value of base metal supply in Canada during this recent period is decidedly negative with more money going "into the ground" in time adjusted terms than coming out.

Reconciliation of Theory and Practice

Economic theory suggests that the choice between base metal exploration and development in the territories and in the provinces should depend on the balancing of incremental costs and benefits. Following this rationale, we would expect to find that the economic attractiveness of mining in the north is comparable to mining activities in southern Canada.

Study results clearly demonstrate, however, that the economic potential associated with mining in the Yukon and Northwest Territories is significantly greater than in the provinces. What explains the contradiction between the theoretical argument and actual experience?

Mineral investment decisions in Canada, whether they are taken by mining companies or governments, are not based on economic theory. Furthermore, mineral exploration strategies concerning "where to look" are seldom founded on any sort of objective economic evaluation. These long-term decisions tend to be mainly influenced by short-term problems and subjective beliefs. The short-term problems usually relate to existing mining operations. The prevailing belief is that "more remote" is "less economic". Consequently, our study findings show that, on the basis of long-term economic potential, there is a strong bias to under-invest in base metal mining in the territories and to over-invest in the provinces.

This reconciliation of study findings and theoretical expectations is of more general significance than the case study itself. It would therefore be surprising if the comparative results for base metal potential in the

territories and provinces did not, to some degree, more generally apply in Canada to:

- other high and medium unit value mineral commodities;
- less-accessible regions versus established mining districts within the provinces and within the territories.

Beyond these boundaries, we can only conclude that "more remote" does not necesarily mean "less economic". Each less-accessible geographic situation - whether Brazil's Amazon basin or the interior desert plains of Australia, for example - would have to be objectively analyzed with respect to competing developed regions and mineral commodities of interest.

Implications for Corporate Planning and Government Policy

The study findings have long-term implications for strategic planning in mining companies. During the 1980s, attention has focused as never before on productivity improvement and the competitive position of Canada's mining industry in international markets. Both the associated investment and the positive results achieved, which in some cases are substantial, have mainly concentrated on existing operations. Mineral exploration has been increasingly directed toward established mining districts to protect mining assets, processing plants, and related infrastructure. This type of corporate strategy, which is of a defensive and short-term nature, has been remarkably successful in enabling the Canadian mining industry to survive a prolonged world-wide market recession.

Looking ahead through the 1990s, to the turn of the century and beyond, there will, however, be a different set of requirements for survival and prosperity. Higher-quality mineral deposits are the key ingredient for enhancing mining productivity and strengthening competitive standing in the longer term. Study results show the economic advantages of finding and developing mineral deposits in frontier regions such as the Yukon and Northwest Territories. To realize this superior economic potential, Canadian mining companies will have to shift their attention away from shoring up existing assets and sunk costs, towards the wealth-creating

opportunities that await sucessful exploration and development in northern Canada.

Mining companies cannot, however, take this initiative entirely on their own. Government has an important up-front role to play in providing the necessary network of regional infrastructure. A broad program of public sector investment appears to be justifiable based on the economic potential assessed in this study.

The federal government's Northern Mineral Policy provides a coherent and logical framework to promote realization of the mineral potential of the Yukon Territory and the Northwest Territories.[3] Government funding and appropriate government programs are now required to give the policy meaning.

An improved transportation system is the key to stimulating a major advance in base metal mining in the territories. The most critical requirement is the construction of all-weather road networks from the southern and western fringes of the region into the hinterland. Another economic priority for large-scale base metal development is the provision of regional power generating facilities. These are the two areas where government investment would have the greatest impact on the economic climate for base metal mining in the north.

With respect to the future realization of economic potential, the northeast Mackenzie district stands out in our study results as a high-priority locus for government investment in infrastructure. Limited exploration carried out to date has revealed extensive and high quality base metal discoveries including one world-class deposit (Izok Lake). The region also contains a world-class gold mine (Lupin), several other prospective gold projects, and is presently the centre of a high level of gold exploration. Given the provision of regional road and power facilities, there is little doubt that the northeast Mackenzie district will be an important part of Canada's long-term mining future.

Broad long-term regional development programs are needed to facilitate mining developments by sharing the cost of common infrastructure facilities among mining projects and over time. Selection of types of program, rates of expenditure, and regional priorities should be based on objective, factual economic appraisals of feasible alternatives. A more detailed version of the study methodology and data base could be applied, for example, to measure the direct effects of possible

[3] *The Northern Mineral Policy*, Indian and Northern Affairs Canada, December 1986, 31 pp.

program options. Government expenditures, apart from their primary justification in terms of the broader economic and social benefits anticipated, should be considered as a viable direct investment, recoverable in user fees over a long period (30-40 years, say).

The attractiveness of base metal mining potential in the territories presents Canada with a great long-term challenge. This is an issue on which there is much common ground between industry and government. An unrivaled opportunity exists for:

- productivity improvement and profitable mining company investment in exploration and mine development;
- supporting economic development of the Yukon and Northwest Territories and improvements in the well-being of northern residents;
- strengthening Canada's competitive position in world mineral markets;
- wealth creation for Canadian society.

We must recognize, however, that realizing this opportunity is not going to be easy. It will require a change in corporate strategy and the implementation of a major government investment program. In no small measure will the vitality of the Canadian mineral economy in the year 2000 depend on the extent to which these changes are made and to which the economic potential of our northern mining frontier is realized.

Bibliography

Anders, G., *On the Economic Development of Canada's Northwest Territories*, unpublished Ph.D. thesis, Texas A and M University, 1972, 189 pp.

Boldy, J., "(Un)Certain Exploration Facts and Figures", *CIM Bulletin*, 1977, no. 5, pp. 86-95.

Boldy, J., "Prospecting for Deep Volcanogenic Ore', *CIM Bulletin*, 1981, no. 10, pp. 56-65.

Brown, D.D. and T.W. Caine, "The Mining Industry in Canada's Northern Territories - Past, Present, and Future", *CIM Directory, 1986*, pp. 67-92.

Buck, W. Keith, *Factors Influencing the Mineral Economy of Canada: Past, Present and Future*, MR 106, Energy Mines and Resources Canada, Ottawa, 1970.

Canalog, *Northeast Mackenzie District Transportation Study, Phase II: Assessment of Transportation Options*, Montreal, August 1980, 57 pp. and appendices.

Centre for Resource Studies, *Mining Communities: Hard Lessons for the Future*, Proceedings No. 14, Centre for Resource Studies, Kingston, 1984, 211 pp.

Cranstone, D.A., *Canadian Ore Discoveries 1946-1978: A Continuing Record of Success*, mineral policy internal report MRI 80/5, Energy, Mines and Resources Canada, January 1980, 21 pp.

Cranstone, D.A., "Canadian Mineral Discovery Experience Since World War II", paper presented at International Institute for Applied Systems Analysis, Laxenburg, Austria, December 1983.

Derry, D.R., "Exploration Expenditure, Discovery Rates and Methods", *CIM Bulletin*, March 1970, pp. 362-368.

Derry, D.R. and J.K.B. Booth, "Mineral Discoveries and Exploration Expenditures - a Revised Review, 1966-76", *Mining Magazine*, May 1978, pp. 430-433.

Dubose, L., *Northeast Mackenzie District Transportation Study: Phase I*, Department of Indian Affairs and Northern Development, Ottawa, March 1979, 71 pp.

Energy, Mines and Resources Canada, *Mineral Policy: A Discussion Paper*, December 1981, 157 pp.

Energy, Mines and Resources Canada, *The Mineral and Metal Policy of the Government of Canada*, May 1987, 13 pp.

Indian and Northern Affairs Canada, *The Northern Mineral Sector: A Framework for Discussion*, Ottawa, March 1985, 37 pp.

Indian and Northern Affairs Canada, *Northern Mineral Policy*, December 1986, 31 pp.

Lazarovich, J. et al, "Mineral Development: Infrastructure and the Role of Government", in *Proceedings of the Second Arctic Transportation Conference*, Whitehorse, 1983.

Lightfoot, R.N., "Transportation Requirements for Remote Projects", paper presented at Prospectors and Developers Association annual meeting, Toronto, March 1985, 18 pp.

Mackenzie, B.W., M.L. Bilodeau and L.J. Verleun, *Base Metal Potential North of 60: Economic Viability, Endowment Quality, Competitive Position*, final report prepared for Indian and Northern Affairs Canada, Centre for Resource Studies, Kingston, March 1984, 102 pp.

Mackenzie, B.W. and M.L. Bilodeau, *Effects of Taxation on Base Metal Mining in Canada*, Centre for Resource Studies, Queen's University, Kingston, 1979, 188 pp.

Mackenzie, B.W., *Geological Aspects of Mining Productivity: Canada's Base Metal Resources*, Technical Paper No. 6, Centre for Resource Studies, Queen's University, Kingston, August 1985, 103 pp.

Mackenzie, B.W., D.W. Davis and M.L. Bilodeau, *Effects of Location on the Competitive Position of Mineral Exploration and Development*

Opportunities in Canada, Working Paper No. 35, Centre for Resource Studies, Queen's University, Kingston, April 1986, 72 pp.

Mackenzie, B. and R. Woodall, *Mineral Exploration Economics: The Search for Base Metals in Australia and Canada*, Working Paper No. 40, Centre for Resource Studies, Queen's University, Kingston, September 1987, 112 pp.

Martin, H.L. and L.S. Jen, "Are Ore Grades Declining? The Canadian Experience, 1939-89", paper presented at International Institute for Applied Systems Analysis, Laxenburg, Austria, December 1983, 51 pp.

O'Faircheallaigh, Ciaran, *Mine Infrastructure and Economic Development in North Australia*, Working Paper No. 36, Centre for Resource Studies, Queen's University, Kingston, September 1986, 92 pp.

O'Hara, T.A., "Quick Guides to the Evaluation of Orebodies", *CIM Bulletin*, February 1980, pp. 87-99.

Petersen, U. and R.S. Maxwell, "Historical Mineral Production and Price Trends", *Mining Engineering*, January 1979, pp. 25-34.

Verleun, L.J., *Base Metal Supply Potential in Northern and Southern Canada: A Comparative Economic Study*, unpublished M.Sc. thesis, Queen's University, November 1984, 198 pp.

Wallace, Iain, *The Transportation Impact of the Canadian Mining Industry*, Centre for Resource Studies, Queen's University, Kingston, 1977, 155 pp.

Wallace, Iain, "Mineral Resource Transportation and Frontier Infrastructure Provision in Canada", pp. 103-116 in *Regional Impacts of Resource Development*, C.C. Kissling et al (eds.), Croom Helm Australia, 1984, 285 pp.

Weinberg, E. et al., *An Inquiry into the Transportation Requirements of Yukon*, Canadian Transport Commission, Ottawa, December 1983, 160 pp.

Weinberg, E., et al., *Final Recommendations of the Inquiry into the Transportation Requirements of Yukon*, Canadian Transport Commission, Ottawa, June 1984, 73 pp.

Willson, J.M., *A Relative Appraisal of the Mining Regime in the Northwest Territories of Canada*, unpublished M.Sc. report, Imperial College of Science and Technology, London, September 1985.

Yudelman, D., *Canadian Mineral Policy Past and Present: The Ambiguous Legacy*, Centre for Resource Studies, Queen's University, 1985, 176 pp.

Yudelman, D., *Canadian Mineral Policy Formulation: A Case Study of the Adversarial Process*, Working Paper No. 30, Centre for Resource Studies, Queen's University, Kingston, May 1984, 77 pp.

APPENDIX I

Table 41

INFLATION MULTIPLIER SERIES USED IN STUDY

Year	Gross National Expenditure Implicit Price Index (1971 = 100)	Inflation Multiplier (1983 = 1.00)
1946	42.0	6.91
1947	45.7	6.35
1948	51.3	5.65
1949	53.5	5.42
1950	54.8	5.29
1951	61.0	4.76
1952	63.7	4.55
1953	64.6	4.49
1954	63.6	4.56
1955	65.0	4.46
1956	67.4	4.30
1957	68.8	4.22
1958	69.8	4.16
1959	71.2	4.07
1960	72.1	4.02
1961	72.4	4.01
1962	73.4	3.95
1963	74.8	3.88
1964	76.6	3.79
1965	79.1	3.67
1966	82.6	3.51
1967	85.9	3.38
1968	88.7	3.27
1969	92.6	3.13
1970	96.9	2.99
1971	100.0	2.90
1972	105.0	2.76
1973	114.6	2.53
1974	132.1	2.20
1975	146.3	1.98
1976	160.5	1.81
1977	171.7	1.69
1983	290.1	1.00

Source: Statistics Canada, *Prices and Price Indexes*, catalogue no. 62-002.

Note: the inflation multiplier is used to convert historical current cost data to 1983 constant money equivalents.

APPENDIX II

BASE METAL EXPLORATION EXPENDITURES

The estimates of total exploration expenditures associated with the base metal deposits discovered during the period 1946-1977 are derived from Statistics Canada data for metallic mineral exploration by province and territory. These estimates are presented in table 42.

To derive base metal exploration expenditure estimates, exploration expenditures for non-study metals - such as gold, silver, nickel, uranium, tungsten and iron ore - are first assessed, then deducted from the metallic mineral totals. The procedure followed in the southern provinces is described in Mackenzie and Bilodeau (1979). Comparable estimates for the northern territories, outlined in Mackenzie et al. (1984), integrate several sources of information, including:

1. Dominion Bureau of Statistics breakdowns of the prospecting costs of metal mining companies in the Yukon and Northwest Territories for the 1946-63 period;

2. time charts of major exploration projects undertaken in the north for each of the non-study metals;

3. company-specific exploration expenditure data, particularly pertaining to nickel exploration;

4. subjective estimates of knowledgeable exploration personnel;

5. annual surveys of uranium exploration expenditures from 1971 by the Uranium Resource Appraisal Group, Energy, Mines, and Resources Canada.

The exploration expenditures assessed for non-study metals are deducted from the metallic mineral expenditures. The resultant base metal expenditures in current dollars are shown in table 43 to enable the reader to compare estimates with the metallic mineral totals in table 42. These expenditures are then converted to constant 1983 dollar values using the inflation multiplier series given in appendix I. The final series is presented in table 44.

Table 42

METALLIC MINERAL EXPLORATION EXPENDITURES
($ current million)

Year	Canada	The Territories	The Provinces
1946	9.1	0.9	8.2
1947	7.3	0.8	6.5
1948	5.1	0.2	4.9
1949	6.4	0.4	6.0
1950	5.4	0.2	5.2
1951	9.2	0.4	8.8
1952	13.6	2.3	11.3
1953	17.8	1.7	16.1
1954	26.8	2.1	24.7
1955	26.9	2.4	24.5
1956	48.4	3.1	45.3
1957	54.4	3.6	50.8
1958	32.5	1.9	30.6
1959	43.0	1.6	41.4
1960	43.6	2.5	41.1
1961	43.5	1.8	41.7
1962	43.8	3.1	40.7
1963	43.5	2.7	40.8
1964	49.0	2.7	46.3
1965	54.0	2.7	51.3
1966	59.0	2.7	66.3
1967	62.7	3.0	59.7
1968	66.5	8.3	58.2
1969	88.9	12.3	76.6
1970	106.0	15.1	90.9
1971	73.0	8.3	64.7
1972	68.9	6.3	62.6
1973	78.4	9.0	69.4
1974	94.5	19.9	74.6
1975	109.7	23.7	86.0
1976	104.9	25.7	79.2
1977	122.8	38.1	84.7

Sources:

i 1946-63 - *Cost of Prospecting by Metal Mining Companies*, annual series prepared by Dominion Bureau of Statistics.Ottawa;

ii 1964-67 - D.A. Cranstone and H.L. Martin, "Are Ore Discovery Costs Increasing?", *Canadian Mining Journal*, April 1973;

iii 1968-77 - derived from *Outside or General Exploration*, annual series prepared from 1968 by Construction Division, Statistics Canada. Ottawa.

Table 43

BASE METAL EXPLORATION EXPENDITURES IN CURRENT DOLLARS ($ current million)

Year	Canada	The Territories	The Provinces
1946	7.4	0.1	7.3
1947	4.7	0.1	4.6
1948	3.4	0.1	3.3
1949	4.5	0.1	4.4
1950	3.6	0.1	3.5
1951	5.0	0.2	4.8
1952	7.2	0.7	6.5
1953	8.2	0.2	8.0
1954	14.2	0.4	13.8
1955	12.2	0.6	11.6
1956	25.2	1.3	23.9
1957	31.4	2.0	29.4
1958	19.4	0.9	18.5
1959	30.0	0.6	29.4
1960	30.1	1.1	29.0
1961	30.4	0.9	29.5
1962	31.0	1.4	29.6
1963	31.4	1.1	30.3
1964	38.1	2.8	35.3
1965	37.3	3.5	33.8
1966	50.8	3.8	47.0
1967	46.3	1.8	44.5
1968	44.8	7.1	37.7
1969	63.8	10.9	52.9
1970	80.6	13.2	67.4
1971	44.7	6.9	37.8
1972	50.0	4.9	45.1
1973	52.2	6.9	45.3
1974	59.2	13.3	45.9
1975	67.5	13.3	54.2
1976	56.8	8.4	48.4
1977	72.2	15.4	56.8

Table 44

BASE METAL EXPLORATION EXPENDITURES IN CONSTANT DOLLARS ($1983 million)

Year	Canada	The Territories	The Provinces
1946	50.9	0.3	50.6
1947	29.8	0.4	29.4
1948	19.5	0.7	18.8
1949	24.6	0.7	23.9
1950	18.9	0.3	18.6
1951	23.9	0.8	23.1
1952	32.6	3.3	29.3
1953	37.1	1.0	36.1
1954	64.9	1.8	63.1
1955	54.4	2.6	51.8
1956	108.7	5.7	103.0
1957	132.5	8.6	123.9
1958	80.5	3.5	77.0
1959	122.4	2.6	119.8
1960	121.1	4.3	116.8
1961	121.8	3.7	118.1
1962	122.7	5.7	117.0
1963	121.9	4.3	117.6
1964	144.2	10.4	133.8
1965	136.9	13.0	123.9
1966	178.4	13.2	165.2
1967	156.3	6.1	150.2
1968	146.6	23.3	123.3
1969	199.8	34.0	165.8
1970	241.3	39.6	201.7
1971	129.6	19.9	109.7
1972	138.2	13.4	124.8
1973	132.0	17.4	114.6
1974	129.9	29.2	100.7
1975	133.9	26.5	107.4
1976	102.7	15.2	87.5
1977	121.9	26.0	95.9

To derive base metal exploration expenditures for the shield and cordilleran regions, appropriate provincial and territorial expenditures are combined. In the north during the period 1968-77, Statistics Canada exploration data are only available for the two territories combined. The allocation of total metallic mineral exploration expenditures between the Yukon and Northwest Territories is based on a synthesis of the following sources of data (Mackenzie et al., 1984):

1. annual surveys of company exploration expenditures compiled by Price Waterhouse Associates for the Yukon Territory since 1960, and for the Northwest Territories from 1975;

2. survey of primary exploration expenditures by province and territory carried out by The Mining Association of Canada in 1979 for the period 1973-76;

3. estimates provided by W.H. Laughlin, Energy, Mines and Resources Canada.

The provincial and terrritorial estimates are then combined as follows. British Columbia and the Yukon Territory are included in the cordilleran region, together with the western edge of the Northwest Territories. Exploration expenditure estimates for Ontario, Manitoba, Saskatchewan, Labrador, part of Quebec, and the remainder of the Northwest Territories are assigned to the shield region. The allocation of exploration expenditures within Quebec and the Northwest Territories is based on subjective estimates of exploration personnel. The resulting exploration expenditure estimates by geological region are summarized in tables 2 and 3 in the text.

APPENDIX III

POSSIBLE ECONOMIC DISCOVERIES FOR EVALUATION

Classification by Geographic Region and Discovery Date

THE TERRITORIES

	Discovery Date			
	Pre-1946	1946-61	1962-69	1970-77
Yukon Territory				
ANNIV				X
ARCTIC CHIEF		X		
BEST CHANCE		X		
CASH				X
CASINO			X	
COWLEY PARK			X	
DY				X
FARO			X	
GEM			X	
GOZ				X
GRUM				X
HART			X	
JASON				X
KEEWENAW		X		
LITTLE CHIEF			X	
MEL				X
MINTO				X
NADALEEN				X
QUARTZ LAKE		X		
SWIM			X	
TOM		X		
VANGORDA		X		
WAR EAGLE			X	
WILLIAMS CREEK				X

THE TERRITORIES (continued)

	Discovery Date			
	Pre-1946	1946-61	1962-69	1970-77
Northwest Territories				
AGRICOLA				X
BEAR-TWIT				X
CONWEST 408			X	
CORONET			X	
DEB				X
DIANNE				X
ECLIPSE		X		
GAYNA				X
GREAT SLAVE REEF				X
HACKETT A			X	
HACKETT BOOT				X
HACKETT CLEAVER				X
HENINGA				X
HIGH LAKE		X		
HOOD 10				X
HOOD 41				X
HOOD 462				X
HOWARDS PASS				X
INDIAN MOUNTAIN		X		
IZOK				X
JAY				X
JUNE			X	
NANISIVIK		X		
PINE POINT 1		X		
PINE POINT 2			X	
PINE POINT 3				X
PINE POINT 4				X
POLARIS				X
PRAIRIE CREEK			X	
PYRAMID			X	
REDSTONE			X	
TURNBACK	X			
WRECK			X	

	Discovery Date			
	Pre-1946	1946-61	1962-69	1970-77
Newfoundland				
BUCHANS	X			
CAPE RAY				X
DANIEL'S HARBOUR			X	
EAST			X	
GREAT BURNT LAKE			X	
GULLBRIDGE	X			
LITTLE BAY	X			
MCLEAN		X		
MING				X
ORIENTAL NO. 2		X		
RAMBLER MAIN	X			
ROTHERMERE		X		
TILT COVE	X			
WHALESBACK		X		
Nova Scotia				
GAY'S RIVER				X
SALMON RIVER			X	
STIRLING	X			
WALTON		X		
New Brunswick				
BRUNSWICK 6		X		
BRUNSWICK 12		X		
CARIBOU		X		
CLEARWATER		X		
HALFMILE LAKE		X		
KEY ANACON		X		
LITTLE RIVER		X		
MURRAY BROOK		X		
STRATMAT			X	
THIRD PORTAGE LAKE		X		
WEDGE		X		
Quebec				
ALDERMAC	X			
AMOS	X			
AMULET A	X			
AMULET C	X			
AMULET F	X			
ANGLO AMERICAN		X		
BARVALLEE		X		
BARVUE		X		
BELFORT		X		
BELL ALLARD		X		
BOUZAN		X		

	Discovery Date			
	Pre-1946	1946-61	1962-69	1970-77
Quebec (continued)				
CAMPBELL MAIN	X			
CAPELTON	X			
CEDAR BAY	X			
CHIBOUGAMAU EXPLORERS		X		
CONIAGAS		X		
COOKE			X	
COPPER CLIFF		X		
COPPER RAND		X		
CORBET		X		
CUPRA		X		
DELBRIDGE			X	
DETOUR A1				X
DETOUR A2				X
DETOUR B				X
DIXIE				X
DUNRAINE	X			
EAST SULLIVAN	X			
EAST WAITE		X		
EUSTIS	X			
GARON LAKE		X		
GASPE COPPER MOUNTAIN	X			
GOLDEN MANITOU	X			
GRANDROY		X		
GRASSET LAKE				X
GWILLAM				X
HENDERSON		X		
HORNE	X			
HUNTINGTON		X		
ICON			X	
JACULET		X		
JOLIET	X			
JOUTEL		X		
KOKKO CREEK		X		
LACORNE	X			
LEMOINE				X
LESSARD				X
LOUVEM			X	
LOUVEM ZINC				X
MADELEINE			X	
MAGUSI				X
MATTAGAMI		X		
MERRILL ISLAND	X			
MILLENBACH			X	
NEEDLE MOUNTAIN	X			
NEW CALUMET	X			
NEW HOSCO		X		
NEW INSCO				X
NORBEC		X		
NORITA			X	
NORMETAL	X			

THE PROVINCES (continued)

	Discovery Date			
	Pre-1946	1946-61	1962-69	1970-77
Quebec (continued)				
OLD WAITE	X			
ORCHAN		X		
PERRY		X		
POIRIER		X		
PORTAGE		X		
PREISSAC	X			
QUEBEC CHIBOUGAMAU		X		
QUEMONT	X			
RIOCANEX OBALSKI				X
ROBITAILLE	X			
SCOTT				X
SOLBEC		X		
SPRINGER	X			
SUFFIELD	X			
VAUZE		X		
VENDOME		X		
WAITE DUFAULT	X			
WEEDON	X			
WEST MACDONALD	X			
Ontario				
BIG NAMA CREEK		X		
BRUCE	X			
COLDSTREAM		X		
COPPERCORP		X		
COPPER-LODE A			X	
COPPER-LODE E			X	
ERRINGTON	X			
F GROUP				X
GECO		X		
JAMELAND			X	
JAMIESON			X	
KAM KOTIA	X			
KIDD CREEK			X	
LYON LAKE				X
MATTABI			X	
MUNRO COPPER		X		
PATER		X		
SCHUMACHER COPPER		X		
SOUTH BAY			X	
STURGEON				X
TEMAGAMI		X		
TRIBAG			X	
VERMILLION	X			
WILLECHO		X		
WILLROY		X		

THE PROVINCES (continued)

	Discovery Date			
	Pre-1946	1946-61	1962-69	1970-77
Manitoba				
ANDERSON LAKE			X	
BOB	X			
CENTENNIAL			X	
CHISEL LAKE		X		
COPPER-MAN	X			
CUPRUS	X			
DICKSTONE	X			
EMBURY LAKE				X
FLIN FLON	X			
FOX		X		
GHOST LAKE		X		
HYERS ISLAND	X			
JUNGLE		X		
LOST LAKE				X
NORTH STAR		X		
OSBORNE LAKE		X		
PINE BAY		X		
RAIL LAKE			X	
REED LAKE			X	
ROD			X	
RUTTAN			X	
SCHIST LAKE		X		
SHERRIDON	X			
SPRUCE POINT				X
STALL		X		
SYLVIA				X
VAMP LAKE	X			
WESTARM				X
WHITE LAKE			X	
WIM			X	
Saskatchewan				
BIRCH LAKE		X		
CORONATION		X		
FLEXAR		X		
WADEN BAY		X		
British Columbia				
ADANAC			X	
AFTON				X
ANNEX			X	
BELL			X	
BENSON			X	
BERG			X	
BETHLEHEM		X		
BIG BULL & TULSEQUAH CHIEF	X			
BLUEBELL		X		
BLUE GROUSE		X		

	Discovery Date			
	Pre-1946	1946-61	1962-69	1970-77
British Columbia (continued)				
BONANZA	X			
BOSS MOUNTAIN			X	
BRENDA			X	
BRITANNIA	X			
CARIBOO BELL			X	
CATFACE			X	
CHUCHUA CREEK				X
CIRQUE				X
COPPER MOUNTAIN	X			
CRAIGMONT		X		
DAVIS KEAYS			X	
ENDAKO			X	
GALORE CREEK			X	
GIBRALTAR			X	
GLACIER GULCH		X		
GOLDSTREAM				X
GRANDUC		X		
GRANISLE			X	
HARPER CREEK			X	
HB		X		
HIDDEN CREEK	X			
HIGHMONT			X	
HUCKLEBERRY			X	
INDIAN CHIEF	X			
INGERBELLE			X	
ISLAND COPPER			X	
JA				X
JERSEY		X		
KITSAULT		X		
KUTCHO CREEK		X		
LORNEX			X	
LUCKY JIM	X			
LYNX		X		
MAGGIE				X
MAGNUM		X		
MINERAL KING		X		
MORRISON			X	
MOTHER LODE & SUNSET	X			
MYRA FALLS				X
OK			X	
ORO DENORO	X			
PHOENIX	X			
RED				X
RED MOUNTAIN			X	
REEVES	X			
ROBB LAKE				X
SAM GOOSLY			X	
SCHAFT CREEK			X	

THE PROVINCES (continued)

	Discovery Date			
	Pre-1946	1946-61	1962-69	1970-77
British Columbia (continued)				
SILVER GIANT	X			
SNOWSHOE	X			
SULLIVAN	X			
SUNRO		X		
SUSTUT				X
TROJAN	X			
TROUT LAKE				X
VALLEY COPPER			X	

Classification by Geological Region and Deposit Type

SHIELD REGION

	Deposit Type			
	Volcanic Associated	Sediment Hosted	Porphyry	Other Types
The Territories				
AGRICOLA	X			
DEB	X			
DIANNE				X
HACKETT A	X			
HACKETT BOOT	X			
HACKETT CLEAVER	X			
HENINGA	X			
HIGH LAKE	X			
HOOD 10	X			
HOOD 41	X			
HOOD 462	X			
INDIAN MOUNTAIN	X			
IZOK	X			
JUNE				X
NANISIVIK		X		
TURNBACK	X			
WRECK				X
The Provinces				
ALDERMAC	X			
AMOS	X			
AMULET A	X			
AMULET C	X			
AMULET F	X			
ANDERSON LAKE	X			
ANGLO AMERICAN				X
BARVALLEE	X			
BARVUE	X			
BELFORT	X			
BELL ALLARD	X			
BIG NAMA CREEK	X			
BIRCH LAKE	X			
BOB	X			
BOUZAN				X
BRUCE	X			
CAMPBELL MAIN				X
CEDAR BAY				X
CENTENNIAL	X			
CHIBOUGAMAU EXPLORERS				X
CHISEL LAKE	X			
COLDSTREAM	X			
CONIAGAS	X			
COOKE				X
COPPER CLIFF				X
COPPERCORP	X			
COPPER-LODE A	X			
COPPER-LODE E	X			

SHIELD REGION (continued)

	Deposit Type			
	Volcanic Associated	Sediment Hosted	Porphyry	Other Types
THE PROVINCES (continued)				
COPPER-MAN	X			
COPPER RAND				X
CORBET	X			
CORONATION	X			
CUPRUS	X			
DELBRIDGE	X			
DETOUR A1	X			
DETOUR A2	X			
DETOUR B	X			
DICKSTONE	X			
DIXIE	X			
DUNRAINE				X
EAST SULLIVAN	X			
EAST WAITE	X			
EMBURY LAKE	X			
ERRINGTON		X		
F GROUP	X			
FLEXAR	X			
FLIN FLON	X			
FOX	X			
GARON LAKE	X			
GECO	X			
GHOST LAKE	X			
GOLDEN MANITOU	X			
GRANDROY				X
GRASSET LAKE	X			
GWILLAM				X
HENDERSON				X
HORNE	X			
HYERS ISLAND				X
ICON				X
JACULET				X
JAMELAND	X			
JAMIESON	X			
JOLIET	X			
JOUTEL	X			
JUNGLE	X			
KAM KOTIA	X			
KOKKO CREEK	X			
LACORNE				X
LEMOINE	X			
LESSARD	X			
LOST LAKE	X			
LOUVEM	X			
LOUVEM ZINC	X			
LYON LAKE	X			
MAGUSI	X			
MATTABI	X			
MATTAGAMI	X			
MERRILL ISLAND				X

SHIELD REGION (continued)

	Deposit Type			
	Volcanic Associated	Sediment Hosted	Porphyry	Other Types
THE PROVINCES (continued)				
MILLENBACH	X			
MUNRO COPPER	X			
NEW CALUMET		X		
NEW HOSCO	X			
NEW INSCO	X			
NORBEC	X			
NORITA	X			
NORMETAL	X			
NORTH STAR	X			
OLD WAITE	X			
ORCHAN	X			
OSBORNE LAKE	X			
PATER	X			
PERRY				X
PINE BAY	X			
POIRIER	X			
PORTAGE				X
PREISSAC				X
QUEBEC CHIBOUGAMAU				X
QUEMONT	X			
RAIL LAKE	X			
REED LAKE	X			
RIOCANEX OBALSKI				X
ROBITAILLE				X
ROD	X			
RUTTAN	X			
SCHIST LAKE	X			
SCHUMACHER COPPER				X
SCOTT	X			
SHERRIDON	X			
SOUTH BAY	X			
SPRINGER				X
SPRUCE POINT	X			
STALL	X			
STURGEON	X			
SYLVIA	X			
TEMAGAMI	X			
TRIBAG				X
VAMP LAKE	X			
VAUZE	X			
VENDOME	X			
VERMILLION		X		
WADEN BAY				X
WAITE DUFAULT	X			
WESTARM	X			
WEST MACDONALD	X			
WHITE LAKE	X			
WILLECHO	X			
WILLROY	X			
WIM	X			

CORDILLERAN REGION

	Deposit Type			
	Volcanic Associated	Sediment Hosted	Porphyry	Other Types
The Territories				
ANNIV		X		
ARCTIC CHIEF				X
BEAR-TWIT		X		
BEST CHANCE				X
CASH			X	
CASINO			X	
COWLEY PARK				X
DY		X		
FARO		X		
GAYNA		X		
GEM				X
GOZ		X		
GRUM		X		
HART			X	
HOWARDS PASS		X		
JASON		X		
JAY				X
KEEWENAW				X
LITTLE CHIEF				X
MEL		X		
MINTO				X
NADALEEN		X		
PRAIRIE CREEK				X
QUARTZ LAKE		X		
REDSTONE				X
SWIM		X		
TOM		X		
VANGORDA		X		
WAR EAGLE				X
WILLIAMS CREEK				X
The Provinces				
ADANAC			X	
AFTON			X	
ANNEX		X		
BELL			X	
BENSON				X
BERG			X	
BETHLEHEM			X	
BIG BULL & TULSEQUAH CHIEF	X			
BLUEBELL		X		
BLUE GROUSE				X
BONANZA	X			
BOSS MOUNTAIN			X	
BRENDA			X	
BRITANNIA	X			
CARIBOO BELL			X	
CATFACE			X	
CHUCHUA CREEK	X			

	Deposit Type			
	Volcanic Associated	Sediment Hosted	Porphyry	Other Types
The Provinces (continued)				
CIRQUE		X		
COPPER MOUNTAIN			X	
CRAIGMONT				X
DAVIS KEAYS				X
ENDAKO			X	
GALORE CREEK			X	
GIBRALTAR			X	
GLACIER GULCH			X	
GOLDSTREAM	X			
GRANDUC				X
GRANISLE			X	
HARPER CREEK				X
HB		X		
HIDDEN CREEK	X			
HIGHMONT			X	
HUCKLEBERRY			X	
INDIAN CHIEF				X
INGERBELLE			X	
ISLAND COPPER			X	
JA			X	
JERSEY		X		
KITSAULT			X	
KUTCHO CREEK				X
LORNEX			X	
LUCKY JIM		X		
LYNX	X			
MAGGIE			X	
MAGNUM				X
MINERAL KING		X		
MORRISON			X	
MOTHER LODE & SUNSET				X
MYRA FALLS	X			
OK				X
ORO DENORO				X
PHOENIX				X
RED			X	
RED MOUNTAIN				X
REEVES		X		
ROBB LAKE		X		
SAM GOOSLY			X	
SCHAFT CREEK			X	
SILVER GIANT		X		
SNOWSHOE				X
SULLIVAN		X		
SUNRO				X
SUSTUT				X
TROJAN				X
TROUT LAKE				X
VALLEY COPPER			X	

	Deposit Type			
	Volcanic Associated	Sediment Hosted	Porphyry	Other Types
The Territories				
CONWEST 408		X		
CORONET		X		
ECLIPSE		X		
GREAT SLAVE REEF		X		
PINE POINT 1		X		
PINE POINT 2		X		
PINE POINT 3		X		
PINE POINT 4		X		
POLARIS		X		
PYRAMID		X		
The Provinces				
BRUNSWICK 6	X			
BRUNSWICK 12	X			
BUCHANS	X			
CAPELTON	X			
CAPE RAY	X			
CARIBOU	X			
CLEARWATER	X			
CUPRA	X			
DANIEL'S HARBOUR		X		
EAST	X			
EUSTIS	X			
GAY'S RIVER		X		
GASPE COPPER MOUNTAIN				X
GREAT BURNT LAKE	X			
GULLBRIDGE	X			
HALFMILE LAKE	X			
HUNTINGTON	X			
KEY ANACON	X			
LITTLE BAY	X			
LITTLE RIVER	X			
MADELEINE				X
MCLEAN	X			
MING	X			
MURRAY BROOK	X			
NEEDLE MOUNTAIN				X
ORIENTAL NO. 2	X			
RAMBLER MAIN	X			
ROTHERMERE	X			
SALMON RIVER		X		
SOLBEC	X			
STIRLING				X
STRATMAT	X			
SUFFIELD	X			
THIRD PORTAGE LAKE	X			
TILT COVE	X			
WALTON		X		
WEDGE	X			
WEEDON	X			
WHALESBACK	X			

APPENDIX IV

TIME TRENDS BY DISCOVERY METHOD

A more detailed time series classification of base metal discovery methods than presented in the text is shown in tables 45 and 46. These results confirm the findings discussed in chapter 8.

Table 45

TIME TRENDS IN DISCOVERY METHODS IN THE TERRITORIES

Time Interval	Number of Discoveries	Discovery Method (percent)			
		Prospecting	Geological	Geophysical	Geochemical
pre-1946	1	100	-	-	-
1946-50	1	100	-	-	-
1951-55	3	100	-	-	-
1956-60	4	100	-	-	-
1961-65	10	70	-	30	-
1966-70	12	58	8	34	-
1971-77	26	50	12	15	23
Total	57	63	7	19	11

Table 46

TIME TRENDS IN DISCOVERY METHODS IN THE PROVINCES

Time Interval	Number of Discoveries	Discovery Method (percent)			
		Prospecting	Geological	Geophysical	Geochemical
pre-1946	61	93	2	5	-
1946-50	14	92	-	8	-
1951-55	32	52	7	38	3
1956-60	30	21	7	68	4
1961-65	32	44	6	38	12
1966-70	31	39	13	39	9
1971-77	34	21	11	61	7
Total	234	53	7	35	5

APPENDIX V

GEOLOGICAL REGIONS AND DEPOSIT TYPES

Geological Regions

Geological regions are first defined by geographic area, then by their geological settings and deposit types. Each region includes a number of specific geological settings that determine which deposit types are most likely to occur. Geological setting is described in terms of tectonics, structure, stratigraphy, lithology, and age.

The four main geological regions in Canada which are prospective for base metal deposits are the shield, cordilleran, appalachian, and platform regions.

The *shield region* occupies nearly half of Canada, forming the bedrock for most of Labrador, Quebec, and Ontario, the northern parts of Manitoba and Saskatchewan, and the central and eastern parts of the Northwest Territories. The shield consists of archean granite-greenstone areas separated and flanked by complex metamorphic zones and geosynclinal belts of proterozoic age. Thus, this environment is generally of precambrian age, formed more than 570 million years ago. However, the shield's archean province, of primary importance in terms of base metal endowment, consists of rocks more than 2,500 million years old. Volcanic-associated deposits of copper and zinc, some containing gold, silver and lead, formed at this time. The shield contains most of Canada's nickel, copper-zinc, gold and iron ore deposits.

The *cordilleran region* includes most of the province of British Columbia, the Yukon Territory, and small western segments of Alberta and the Northwest Territories. This region is also a dominantly geosynclinal and tectonically active belt, composed of rocks of proterozoic, paleozoic, mesozoic and quarternary ages, formed between 2,500 million years and 65 million years ago. The cordilleran region is an important source of porphyry, sediment-hosted, and volcanic-associated base metal deposits.

The *appalachian region* covers the island of Newfoundland, Nova Scotia, New Brunswick, and the province of Quebec south of the St. Lawrence River. This region is mainly composed of rocks of paleozoic age, formed from 570 million years to 225 million years ago in a

tectonically active, geosynclinal belt. The appalachian region is a notable source of both volcanic-associated and sediment-hosted base metal deposits.

The *platform regions* mainly include southwestern Manitoba, most of Saskatchewan and Alberta, the Hudson Bay lowland, and the central-west part of the Northwest Territories. These regions are underlain by relatively young sedimentary rocks that range from clastic sediments to carbonates and evaporates. For study purposes, the innuitian province in the northern half of the arctic archipelago is also included. The only base metal deposits discovered to date in these regions are located in the Northwest Territories. They are all sediment-hosted deposits, most notably in the Pine Point district and at Polaris.

Deposit Types

While geological regions provide a useful geographic focus for mineral exploration, economic targets are more specifically defined by deposit types. The main base metal deposit types of interest in this study are outlined as follows.

Volcanic-associated massive sulphide deposits are defined by three major characteristics: occurrence of mineralization in a stratiform zone of massive sulphides; association of deposits with extrusive submarine volcanic rocks; and deposition of the ore from the discharge waters of submarine hot springs. Volcanic-associated deposits are typically small and high grade. Occurring in active tectonic zones at intervals through the entire geological timeframe, volcanic-associated deposits are found in the shield, appalachian, and cordilleran regions.

Sediment-hosted massive sulphide deposits are defined on the basis of their association with sedimentary host rocks, typically shale or carbonate marine sediments. Sediment-hosted zinc-lead deposits, which may contain copper and silver, are usually of medium size and grade, occurring in sediments formed since about 2,000 million years ago. This deposit type is mainly found in the appalachian, cordilleran, and platform regions.

Porphyry deposits are invariably related, both spatially and genetically, to highly fractured and hydrothermally altered zones in complex high level felsic intrusions within active tectonic belts. Porphyry deposits are typically large and low grade, and may contain copper only, copper-gold, copper-molybdenum, or molybdenum with or without tungsten. This deposit type tends to be identified with relatively young rocks, especially in active mesozoic-tertiary zones such as the cordilleran region. Sub-economic examples of this type are known in the precambrian.

"Other" deposit types include chibougamau, skarn, red bed copper, breccia pipe, native copper in basalt, and copper and molybdenum vein deposits. Lead-zinc-silver vein deposits are not included in the study data base.

APPENDIX VI

MINING TAXATION SYSTEMS

The following description outlines the Canadian taxation regimes existing in 1983 as applied in the study.

Federal Corporate Income Tax

Cash Flow Format:

Revenue
- Operating Cost
- Capital Cost Allowance at 30% db (optional)
- Interest Payments

If negative: Carried Loss (for year X + 1 or X-1)

Revenue
- Operating Cost

Net Income before Allowances
- Capital Cost Allowance
- Inventory Allowance

Resource Profits
- Resource Allowance
- Interest Payments
- Exploration Expenditures
- Development Expenditures

Income for Earned Depletion
- Earned Depletion Allowance
- Carried Loss (from X-1 or X + 1)

Income for Federal Corporate Income Tax
Federal Corporate Income Tax Otherwise Payable
- Investment Tax Credit

Net Federal Corporate Income Tax Payable

Capital Cost Allowance: applied to mine plant and machinery, the mill facility, infrastructure capital, and mine development capital after the start of commercial production. The amount allowable must be reduced by the investment tax credit (see below).

For capital expended during the development stage and for expansions of at least 25% in capacity, the deduction permitted is the greater of 30% per year of the capital cost on a declining-balance basis, or an amount equal to (revenue - operating cost - interest payments) from the new mine, i.e. at 100% against new mine income.

Assume - taxation on an individual project basis will use the 100% rate. Taxation on an integrated company basis will use the 30% rate until new mine income begins and then the balance will be deducted at the 100% rate. Note that while capital cost allowance reduces the amount of resource profits and resource allowance, a carried loss does not. Therefore, using the 30% rate until new mine income begins may be advantageous even on the individual project basis.

For other capital costs (apart from major expansion) and sustaining capital costs, the capital cost allowance is 30% per year on a declining-balance basis for all except mine development capital costs which are allowable at 100%.

Capital expenditures incurred to control air and water pollution can be deducted at 50% per year on a straight-line basis.

Inventory Allowance: 3% of the cost of inventory is allowable each year. Inventory includes operating supplies and the cost of concentrate produced and not sold, but not spare parts. In accounting terms, if working capital (current assets -current liabilities) comprises receivables and inventory, the allowance is determined on the inventory portion.

Assume - 50% of working capital is applicable to the determination of inventory allowance.

Resource Allowance: 25% of resource profits.

Development Expenditures: mine development capital costs incurred before the start of commercial production are allowed to be deducted at 100%.

Earned Depletion Allowance: $1 for every $3 of allowable capital costs and expenditures up to a maximum of 25% of income for earned depletion in any year.

Allowable capital costs and expenditures include exploration expenditures mine development, mine plant and machinery, mill facility, and infrastructure capital at the development stage; mine plant and machinery, and mill facility capital associated with a major expansion; and the processing machinery equipment component in other capital costs (other than major expansions) and sustaining capital costs. The amount allowable must be reduced by the investment tax credit (see below).

Carried Loss: losses may be carried back one year and ahead five years.

Federal Corporate Income Tax: 36% of income for federal tax.

Investment Tax Credit: applies to mine plant and machinery, mill facility and infrastructure capital. The investment tax credit is deducted from the federal corporate income tax which would otherwise be payable to determine the net tax payable. The maximum deduction in any year is $15,000 plus one-half the federal corporate income tax payable.

The basic rate of credit is 7%. This rate applies generally in southern Ontario, southwestern Quebec, and most of Alberta and British Columbia.

The rate of tax credit is 10% in areas designated under the Regional Development Incentives Act in Saskatchewan, Manitoba, northern Ontario, and Quebec other than the Gaspe region. Investments in the northern parts of Alberta and British Columbia, and the Yukon and Northwest Territories also qualify for the credit at this rate.

The rate of tax credit is 20% in the Atlantic Provinces and the Gaspe region of Quebec.

Provincial and Territorial Corporate Income Tax

The Territories

Income for Yukon and Northwest Territories corporate income tax is derived in exactly the same way as income for federal corporate income tax. The applicable tax rate is 10 percent.

The Provinces

QUEBEC

Cash Flow Format:

Revenue
- Operating Cost
- Capital Cost Allowance at 30% db (optional)
- Interest Payments

If negative: Carried Loss (for year X + 1 or X-1)

Revenue
- Operating Cost

Net Income before Allowances
- Capital Cost Allowance
- Inventory Allowance

Resource Profits
- Resource Allowance
- Interest Payments
- Exploration Expenditures
- Development Expenditures

} same format as for Federal Corporate Income Tax

Income for Earned Depletion
- Earned Depletion Allowance
- Carried Loss (from year X-1 or X + 1)

Income for Quebec Corporate Income Tax
Quebec Corporate Income Tax

Capital Cost Allowance
Inventory Allowance
Resource Allowance
Development Expenditures
Carried Loss

} Same rules as for Federal Corporate Income Tax

Earned Depletion Allowance: same rules as for federal corporate income tax except maximum annual deduction is 33 1/3% of income for earned depletion.

Quebec Corporate Income Tax: 13% of income for Quebec income tax.

ONTARIO

Cash Flow Format:

Revenue
- Operating Cost
- Capital Cost Allowance at 30% db (optional)
- Interest Payments

If negative: Carried Loss (for year X + 1 or X-1)

} same format as for Federal Corporate Income Tax

Revenue
- Operating Cost

Net Income before Allowances
- Capital Cost Allowance
- Inventory Allowance
- Interest Payments
- Exploration Expenditures
- Development Expenditures

Income for Percentage Depletion
- Percentage Depletion Allowance
- Carried Loss (from year X-1 or X + 1)

Income for Ontario Corporate Income Tax
Ontario Corporate Income Tax

Capital Cost Allowance
Inventory Allowance
Development Expenditures
Carried Loss

} Same rules as for Federal Corporate Income Tax

Percentage Depletion Allowance: 33 1 3% of income for percentage depletion.

Ontario Corporate Income Tax: 13% of income for Ontario income tax.

OTHER PROVINCES

In British Columbia, resource allowance is not an allowable deduction in calculating income for B.C. corporate income tax. Otherwise, income for provincial corporate income tax is derived in exactly the same way as income for federal corporate income tax.

The applicable tax rates are as follows:

Manitoba	15%
British Columbia	16%
Newfoundland	15%
Nova Scotia	13%
New Brunswick	12%
Saskatchewan	14%

Provincial and Territorial Mining Tax

The Territories

NORTHWEST TERRITORIES

Cash Flow Format:

Revenue
- Operating Cost

Net Income before Allowances
- Depreciation Allowance
- Exploration Expenditures

Income for Processing Allowance
- Processing Allowance

Income for Northwest Territories Mining Tax
Northwest Territories Mining Tax

Depreciation Allowance: all capital costs except post-production mine development capital costs allowable at 15% per year on a straight-line basis; post-production mine development capital costs at 100%.

Processing Allowance: 8% per year of the original cost of processing assets but not to be less than 15% nor more than 65% of the income for processing allowance.

Northwest Territories Mining Tax:

income for mining tax	marginal rate
up to $10,000	exempt
$10,000 - $1 million	3%
$1 million - $5 million	5%
$5 million - $10 million	6%
$10 million and over	+ 1% for each additional $5 million up to 12% maximum

YUKON TERRITORY

Cash Flow Format:

Revenue
- Operating Cost

Net Income before Allowances
- Depreciation Allowance
- Exploration Expenditures

Income for Yukon Mining Tax
Yukon Mining Tax

Depreciation Allowance: all capital costs except post-production mine development capital costs allowable at 15% per year on a straight-line basis; post-production mine development capital costs at 100%.

Yukon Mining Tax:

income for mining tax	marginal rate
up to $10,000	exempt
$10,000 - $1 million	3%
$1 million to $10 million	5%
$5 million - $10 million	6%
$10 million and over	+ 1% for each additional $5 million up to 12% maximum

The Provinces

NEWFOUNDLAND*

Cash Flow Format:

Revenue
- Operating Cost

Net Income before Allowances
- Depreciation Allowance
- Exploration Expenditures

Income for Processing Allowance
- Processing Allowance

Income for Newfoundland Mining Tax
Newfoundland Mining Tax

Depreciation Allowance: all pre-production capital costs allowable on a straight-line basis over estimated mine life. Capital expended during the productive life of a mine is allowable at 10% on a straight-line basis.

Processing Allowance: 8% per year of the original cost of processing assets but not to be more than 65% of the income for processing allowance.

Newfoundland Mining Tax: 20% on first 20% of income for Newfoundland mining tax; 15% on remaining income for Newfoundland mining tax.

* The Iron Ore Company of Canada has a special tax agreement with the Newfoundland government. Their iron ore mining and processing operations in Labrador are taxed at a flat rate of 5% of taxable income. Depreciation allowance is 10% per year of all capital costs on a straight-line basis. There is no processing allowance. Interest and royalty payments are not deductible.

NOVA SCOTIA

Cash Flow Format:

Revenue
- Operating Cost

Net Income before Allowance
- Depreciation Allowance
- Exploration Expenditures

Income for Processing Allowance
- Processing Allowance

Income for Nova Scotia Mining Tax
Nova Scotia Mining Tax

Depreciation Allowance: all capital costs except post-production mine access capital costs allowable at 15% per year on a straight-line basis: post-production mine access capital costs at 100%.

Processing Allowance: 8% per year of the original cost of processing assets but not to be less than 15% nor more than 65% of the income for processing allowance.

Nova Scotia Mining Tax: the greater of 2% of net smelter return or 15% of income for Nova Scotia mining tax (but subject to change by order-in-council).

NEW BRUNSWICK

Cash Flow Format:

Revenue
- Operating Cost
- Royalty
- Depreciation Allowance
- Interest Allowance

Income for Processing Allowance
- Processing Allowance

Income for New Brunswick Mining Tax
New Brunswick Mining Tax Otherwise Payable
- Exploration and Research Credit

New Brunswick Mining Tax Payable

Royalty: 2% of "net mill return"

Gross Metal Revenue
- Smelting, Refining, and Transportation Charges

Revenue
- Mill Operating Costs

Net Mill Return (i.e. value of the mill feed)

Depreciation Allowance: includes all capital expenditures except exploration, research and development, and working capital. Allowable at up to 100% but not to be less than 5% per year. Assume maximum possible allowance taken.

Interest Allowance: 8% per year of the undepreciated cost of all assets qualifying for depreciation allowance. Note that it may in some cases be advantageous to depreciate more slowly than possible to take fuller advantage of this allowance.

Processing Allowance: annual rate applied to the original cost of processing assets but not to be less than 15% nor more than 65% of income for processing allowance.

6% of concentrator assets.
9% of smelter assets.

New Brunswick Mining Tax:

income for mining tax	marginal rate
up to $100,000	exempt
$100,000 and over	16%

Exploration and Research Credit: 25% of exploration costs, and research and development expenditures.

QUEBEC

Cash Flow Format:

Revenue
- Operating Cost
- Depreciation Allowance
- Exploration Expenditures (optional)

Carried Loss

Revenue
- Operating Cost
- Depreciation Allowance
- Exploration Expenditures

Income for Exploration and Investment Allowance
- Exploration and Investment Allowance

Income for Processing Allowance
- Processing Allowance

Income for Quebec Mining Tax
Quebec Mining Tax Otherwise Payable
- Deduction for Carried Loss

Net Quebec Mining Tax Payable

Depreciation Allowance: mine development capital costs at 100% per year; all other capital costs at 30% per year on a straight-line basis.

Exploration and Investment Allowance: $1 for every $3 of pre-production exploration expenditures, capital costs of processing facilities, and exploration costs incurred at operating underground mines, up to a maximum of 33 1/3% of income for exploration and investment allowance in any year.

Processing Allowance: annual rate applied to the original cost of processing assets but not to be less than 15% nor more than 65% of income for processing allowance.

8% if ore concentrated.

15% if concentrate is further processed in Quebec.

Quebec Mining Tax Otherwise Payable: subject to "tax averaging concept" (see below).

income for mining tax	marginal rate
up to $250,000	exempt
$250,000 - $3,250,000	15%
$3,250,000 - $10,250,000	20%
$10,250,000 - $20,250,000	25%
$20,250,000 and over	30%

Deduction for Carried Loss: 15% of "carried loss" in the year following the loss. This deduction can be carried forward for a maximum of four years.

Tax Averaging Concept: based on three-year floating average, including the present year. Procedure:

1. determine mining tax payable in present year;
2. determine average annual income for Quebec mining tax for the last three years (including present year) and calculate what mining tax would be payable on this average annual value (note: loss years count as nil tax).
3. multiply (2) by 3 and deduct taxes actually paid the past two years (excluding present year);
4. pay the lesser of (1) and (3) in the present year.

ONTARIO

Cash Flow Format:

Revenue
- Operating Cost

Net Income before Allowances
- Depreciation Allowance
- Exploration Expenditures

Income for Processing Allowance
- Processing Allowance

Income for Ontario Mining Tax
Ontario Mining Tax

Depreciation Allowance: mine development capital costs at 100% per year; mine plant and equipment at 30% per year on a straight-line basis: mill, infrastructure and all other capital costs at 15% per year on a straight- line basis (and not to be less than 5% per year, irrespective of net income before allowance).

Processing Allowance: annual rate applied to the original cost of processing assets but not to be less than 15% nor more than 65% of income for processing allowance.

8% if ore concentrated.
16% if ore smelted.
20% if ore refined.
30% if ore refined in northern Ontario.
35% if ore fabricated in northern Ontario.

Ontario Mining Tax:

income for mining tax	marginal rate
up to $250,000	exempt
$250,000 - $1 million	15%
$1 million - $10 million	20%
$10 million - $20 million	25%
$20 million and over	30%

MANITOBA

Cash Flow Format:

Revenue
- Operating Cost

Net Income before Allowances
- Depreciation Allowance
- Exploration Expenditures

Income for Processing Allowance
- Processing Allowance

Income for Manitoba Mining Tax
Manitoba Mining Tax Otherwise Payable
- Investment Tax Credit

Net Manitoba Mining Tax Payable

Depreciation Allowance: all capital costs (net of investment tax credit) at 20% per year on a declining-balance basis.

Processing Allowance: average of 8% per year of the original cost of processing assets but not to be less than 15% nor more than 65% of income for processing allowance.

Manitoba Mining Tax: 18% of income for Manitoba mining tax.

Investment Tax Credit: 5% of capital expenditures on mine development, mine plant and machinery, and processing assets, which have been made for the purposes of bringing a new mine into production, carrying out a major expansion, or "modernizing" existing facilities to increase production potential.

Allowable capital costs for "depreciation allowances" must be reduced by the amount of the investment tax credit.

The investment tax credit may be deducted in the year a qualified asset is acquired and can be carried forward for another five years.

SASKATCHEWAN (metallic minerals)

Cash Flow Format:

Revenue
- Operating Cost

Net Income before Allowances
- Depreciation Allowance
- Exploation Expenditures

Income for Processing Allowance
- Processing Allowance

Income for Saskatchewan Mining Tax
Saskatchewan Mining Tax

Depreciation Allowance: all capital costs except post-production mine development capital costs allowable at 15% per year on a straight-line basis; post-production mine development capital costs at 100%.

Processing Allowance: 8% per year of the original cost of processing assets but not to be less than 20% nor more than 65% of the income for processing allowance for copper-zinc deposits, and not to be less than 15% or more than 65% of income for other deposits.

Saskatchewan Mining Tax:

income for mining tax	marginal rate
up to $25,000	exempt
$25,000 - $100,000	5%
$100,000 - $500,000	7%
$500,000 and over	9%

BRITISH COLUMBIA

Cash Flow Format:

Revenue
- Operating Cost

Net Income before Allowances
- Depreciation Allowance
- Exploration Expenditures

Income for Processing Allowance
- Processing Allowance

Income for Earned Depletion Allowance
- Earned Depletion Allowance

Income for British Columbia Mining Tax
British Columbia Mining Tax

Depreciation Allowance: all capital costs at 30% per year on a declining-balance basis.

Processing Allowance: 8% per year of the original cost of processing assets but not to be less than 15% nor more than 50% of income for processing allowance.

Earned Depletion Allowance: calculated in the same manner as for federal corporate income tax.

British Columbia Mining Tax: 17.5% of income for mining tax.

Note: all allowances must be taken on an individual project basis.

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Monographs and Collections

Conflict and its Resolution in the Administration of Mineral Resources in Canada, by R.M. Burns; 62 pages, 11 tables, 1976.

The Impact of the Mining Industries on the Canadian Economy, by R.W. Boadway and J.M. Treddenick; 116 pages, 15 tables, 1977.

The Transportation Impact of the Canadian Mining Industry, by A.I. Wallace; 154 pages, 17 tables, 1977.

Human Resources in Canadian Mining: A Preliminary Analysis, by J.A. MacMillan, G.S. Gislason, and S. Lyon; 174 pages, 48 tables, 1977.

Health and Safety in the Canadian Mining Industry, by G.W. Gibbs and P. Pintus; 248 pages, 58 tables, 1978.

The Canadian Nonferrous Metals Industry: An Industrial Organization Study, by E. Urquhart; 158 pages, 18 tables, 1978.

Economic Impacts and Linkages of the Canadian Mining Industry, by P.E. Nickel, et al.; 140 pages, 31 tables, 1978.

Environmental Impact of Mining in Canada, by E.A. Ripley, et al., 274 pages, 45 tables, 1978, reprinted 1982.

Effects of Taxation on Base Metal Mining in Canada, by B.W. Mackenzie and M.L. Bilodeau; 188 pages, 29 pages, 29 tables, 1979.

Gold: The World Industry and Canadian Corporate Strategy, by E. Cousineau and P.R. Richardson, 192 pages, 32 tables, 1980.

The Impact of Policy Change on Decisions in the Mineral Industry: The Case of Exploration in Manitoba, 1969-77, by B.E. Owen and W.J. Kops; 116 pages, 8 tables, 1980.

The Role of Mineral Taxation in Industry/Government Conflict: The Case of the Saskatchewan Potash Reserve Tax, by David L. Anderson; 135 pages, 41 tables, 2 illustrations, 1981.

Profitability in the Canadian Mineral Industry, by Charles H. Pye; 178 pages, 42 tables, 12 illustrations, 1981.

Foreign Investment Control in the Canadian Mineral Sector: Lessons from the Australian Experience, by David L. Anderson; 180 pages, 22 tables, 1983.

Financing Canadian Mining in the Eighties: Strategies for Action, edited by David Yudelman; 240 pages, with papers by B. Bradly, A. Dorland, J. Erola, P. Gillin, P. Glenshaw,

S. Greenwald, B. Kalymon, P. MacCulloch, B. Mackenzie, K. Murphy, A. Powis, R. Sultan, and D. Yudelman, 1984.

National Resources and International Bargaining Power: Canada's Mineral Policy Options, by Patrick James Caragata; 190 pages, 1984.

Canadian Mineral Policy Past and Present: The Ambiguous Legacy, by David Yudelman; 188 pages, 1985.

An Analysis of Japanese Coking Coal Procurement Policies: the Canadian and Australian Experience, by David L. Anderson; 221 pages, 1987.

The Korean Mineral Market: Opportunities and Marketing Strategies for Canada, by O. Yul Kwon; 177 pages, 1987.

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